VOLUME 87 NO. SA2
MARCH 1961
PART 1

JOURNAL of the

Sanitary Engineering Division

PROCEEDINGS OF THE

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OF CIVIL ENGINEERS

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This Journal is published bi-monthly by the American Society of Civil Engineers. Publication office is at 2500 South State Street, Ann Arbor, Michigan. Editorial and General Offices are at 33 West 39 Street, New York 18, New York. $4.00 of a member's dues are applied as a subscription to this Journal. Second-class postage paid at Ann Arbor, Michigan.

The index for 1959 was published as ASCE Publication 1960-10 (list price $2.00); indexes for previous years are also available.

Journal of the

SANITARY ENGINEERING DIVISION

Proceedings of the American Society of Civil Engineers

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RADIOLOGICAL CURRICULA FOR SANITARY ENGINEERS

By John E. Kiker, Jr.,[1] F. ASCE, and F. Wellington Gilcreas[2]

SYNOPSIS

Sanitary engineers should initiate the development and undertake the administration of essential programs for the protection of the public health through the control of environmental pollution caused by radioactivity. Specialized study is necessary in order to assume a position of leadership in this field.

INTRODUCTION

The basic principles of radiation have been known for many years, preceding the use of X-rays and radium for medical purposes at the turn of the century. Although much has since been learned about the effects of radioactive materials on people, consideration of the public health aspects of radiation exposures did not assume major proportions until relatively recently, with the rapid development of nuclear science and industrial uses of nuclear energy. The large amount of research done has provided a storehouse of information regarding the potentialities of radioactivity and the need for control of the widespread and rapidly expanding use of radioactive materials in many phases of our everyday activities. The complexity of the problems involved mades it important that many individuals with widely differing edu-

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cation and interests concern themselves with the questions and procedures of control of the resulting health hazards.

The effect of radiation on people is primarily a medical problem. The safety of the design and operation of nuclear reactors are engineering problems. The disposal of radioactive waste materials from medical institutions, industrial operations, and research organizations is the responsibility of sanity engineers who must be competent in the areas of environmental health and familiar with the production and control of radiation hazards. It is apparent that close cooperation by persons with diverse education and experience is essential. The problem of control is essentially based on team work by groups composed of physicians, physicists, and engineers, including sanitary engineers.

Each is equally important in contributing to the basic responsibility and service of the team as a whole. However, it is the sanitary engineer who is most intimately concerned with the broad public health aspects of the problem. Effects of radiation on human beings and other biological organisms is the direct concern of the physician. Workers exposed to radiation in industry and in research units can be trained to observe safety precautions and can be best supervised by the expert radiation physicist. But the mass of the population of any community must be protected from the hazards of radiation by full control of all environmental factors—air, water, food, and others, and this is the area in which the sanitary engineer has the basic and most effective education and experience.

In many instances the sanitary engineer must assume leadership in programs of control of these new and rapidly expanding public health problems. The hazards of radiation and radioactivity merely contribute an additional element in the scope of sanitary or environmental engineering, yet the complexity of radioactivity and nuclear science require skills which were not usually included in definitions of sanitary engineering until 1954 when the current definition was adopted by the Committee on Sanitary Engineering and Environment of the National Academy of Science—National Research Council. Additional and highly specialized education is required for sanitary engineers who are to be concerned with control of radiation pollution of water, air, food and other components of the environment. This is no way disregards the need for all sanitary engineers to become familiar with the basic principles of nuclear science and the accepted procedures for control of radiation hazards.

The problem of curricula embraces general basic education for all sanitary engineers and specialized instruction for the specialist to be concerned principally with problems of radiological health, and the administration and direction of programs and of groups of workers in this field.

UNDERGRADUATE CURRICULA

The development of a rational curriculum in this relatively new area is not simple. Present curricula in all areas of engineering and particularly in sanitary engineering are already overcrowded. To insert new and highly specialized courses within such crowded programs is difficult because all of the existing courses in the basic phases of engineering and science are also needed. To merely add new courses will overload the student's program beyond reason. In some instances revision of the scope of existing courses is essential. This is particularly true in the undergraduate curriculum where

the initial instruction in radiation problems should begin. For the undergraduate curriculum, the basic science courses, in general, and mathematics, in particular, require greater emphasis and possibly some revision as a foundation for the essential beginning instruction in nuclear science.

An introductory course in modern physics should incorporate the basic principles of nuclear energy and the production of radioactive substances. Similarly, courses in chemistry should include some radiation chemistry. The content of certain specialized sanitary engineering courses, such as industrial waste treatment, can easily be reorganized to provide consideration of radioactive wastes as an industrial problem. A course in the application of laboratory examinations to problems in sanitary engineering should be a part of any well planned curriculum. Here the techniques for detection of radiation and the always important question of adequate sampling can be included readily and without undue disturbance of the scope of existing courses. Such a program will introduce the student to the problems of radioactivity and radiation hazards. The student will then be able to decide if he wishes to pursue this particular phase of sanitary engineering further. If he does not have such an interest, he will have acquired enough knowledge to approach problems of radiation with an intelligent appreciation of what they are all about.

At some institutions, new undergraduate curricula leading to a Bachelor of Engineering Science degree provide almost exactly the courses needed for later specialization in radiation hygiene and hazard control. The programs are generally for superior students and one was started at the University of Florida, Gainesville, Fla., in 1959.

GRADUATE PROGRAMS

In the graduate area more intensified instruction in radiation science must begin. Every sanitary engineer seeking a Master's degree should be oriented in this field and be taught to participate effectively in sanitary engineering programs involving the control of radiation hazards. However, the graduate degree should be based on a major in sanitary engineering, which means that all of the usual phases of this professional program should be continued and that the specialized basic education in nuclear science should be added.

Among the topics which should be included early in this specialized program are the following:

1. The principles of radiation and its production by nuclear fission;
2. the biological, chemical, and physical effects of radiation, particularly on the population, and the limiting, allowable concentrations of radioactive materials in the various phases of the environment;
3. the methods for the detection and measurement of radioactivity in the environment, including a knowledge of the required measuring instruments and their manipulation;
4. the hazards of radiation techniques for protection of the environment, and prevention of pollution from radioactive substance; and
5. the procedures for the elimination or reduction of radioactive contamination in air, water, food, wastes, and other environmental factors.

Much of this needed basic instruction can be given in advanced courses of nuclear physics and radiation chemistry. A course in the biological aspects

of radioactivity and radiation, even if brief, should occupy an important place in the graduate curriculum.

A specialized course concerning the problems of radiation in sanitary engineering and environmental sanitation is basic and should be required of every student studying for a graduate degree in sanitary engineering. The content of such a course must include consideration of the treatment and disposal of radioactive wastes, the effect of such substances on stream uses and on the procedures for the treatment of water and sewage. Of fundamental importance are techniques for radioactive monitoring of water, air and allied substances, and the interpretation of such monitoring data as a basis for programs of control of hazardous conditions. The uses of radioactive isotopes in sanitary engineering, particularly as tracers of pollution in streams, in delineating flow patterns, and in determining the effects of different processes of sewage treatment, are an essential part of such a course. The course should consider not only the potential uses of radioactive isotopes but of greater importance how they can be used effectively and without the production of additional hazards, either to the user or to the environment in which they are used. A course as described should be so developed as to provide approximately six semester hours of credit. It should include lectures and adequate laboratory exercises on sampling, detection, and measuring techniques, and instruction in the use and care of instruments.

A full program for the graduate student would then be provided, since instruction at the graduate level of other phases of sanitary engineering cannot be neglected. An individual qualifying for a graduate degree, usually a Master's degree, will be prepared to assume an active role in programs of radiation control and protection.

DOCTORATE PROGRAMS

It is apparent that further specialized graduate work in radiation hygiene and hazard control is essential for those individuals who are to be responsible for planning and administering programs for the control of radiation hazards. This further instruction should be at the doctoral level and should build on the program described for the Master's degree. The program at this educational level should include a more comprehensive course in the biological aspects of radiation and should be somewhat similar in content to the basic courses given to medical students. A knowledge of these biological problems is indispensable to the sanitary engineer actively concerned with control and protection procedures.

A major part of the program should include actual work in the field of radioactivity as embodied in the kind of research which is an integral part of the qualifications for the Doctorate degree with a sanitary engineering major. The research should be in the area of radiation and radioactivity but should also be related to the basic factors of sanitary engineering. In spite of the vast amount of knowledge that has been accumulated, there is still much to be learned. The field for Doctoral research is almost unlimited and many topics can be selected for which original investigation is required to expand existing data or to develop new data. Once the sanitary engineer is qualified for the Doctoral degree he should be capable of acquiring, by actual experi-

ence, the further education needed to make progress in this new and complex field.

CONCLUSIONS

The control of radiation hazards for the protection of health requires a competent team of specialists, on which the sanitary engineer is an indispensable member. The sanitary engineer should assume leadership in the development and administration of essential programs for the protection of the public health through the control of environmental pollution from radioactivity.

The course work required for the education of the sanitary engineer specializing in radiation problems must be expanded to include not only the accepted phases of engineering and sanitation but also special concentration in the field of radioactivity and nuclear science. Courses in this specialized area should originate in the undergraduate curriculum and be expanded and intensified at the graduate level. In particular, the program at the doctoral level should include problems in radiological research as applied to sanitary engineering and environmental control of radiation hazards. This requires something of a new approach to program planning to include a new and expanding area of sanitation, to provide engineers who are not only generally oriented in this field, but who are also equipped with the essential specialized education which will permit them to assume required positions of leadership.

Sanitary engineers have generally been required to study chemistry more than any engineer but the chemical engineer, more biology or bacteriology than in any other branch of engineering, and as much mathematics as the structural engineer. In addition to this rather full measure of the basic sciences, the sanitary engineer specializing in radiation hygiene and hazard control will have to increase his study of physics beyond that normally required of most other engineers except perhaps those specializing in nuclear engineering.

This does not mean to imply that in chemistry the sanitary engineer is as competent as the chemist or chemical engineer, or in biology and bacteriology as the biologist and bacteriologist, or in mathematics as the graduate-level mathematics major; nor in physics will he become as proficient as the physicist at the graduate level. In the past, the sanitary engineer has always had to lean heavily on the chemist, the biologist, and the bacteriologist, and it is true that most of the basic research in sanitary engineering has been done by these professional groups. In the future, the sanitary engineer may have to lean also on the physicist, particularly the radiation physicist, for much of the basic work and guidance needed in the field of radiation hygiene and hazard control. Just as the chemist and bacteriologist have done most of the fundamental work leading to water quality standards, so should the physicist be expected to contribute the fundamental work leading to radiological standards. The physician will remain responsible for the over-all health program, of course, but he will generally retain the sanitary engineer as his chief staff officer charged with the responsibility of abatement of pollution or contamination. It is no more necessary to make a physicist or a "health physicist" out of a sanitary engineer before he can become effective in ad-

ministering a radiological health program, than it is to make a chemist or bacteriologist out of him before he can administer a stream pollution or air pollution abatment program.

The core courses normally required at one university for a graduate major in radiation hygiene and hazard control are given in Appendix I. Also included is a partial list of elective courses. Similar lists for major work in air pollution, and in water supply and waste water disposal, are given in Appendix II, for the purpose of comparison.

APPENDIX I.—CORE COURSES NORMALLY REQUIRED FOR MAJOR IN RADIATION HYGIENE AND HAZARD CONTROL

Master's Degree:	Credits
Quantitative Analysis[a]	4
Physical Chemistry[a]	3
Introduction to Nuclear Engineering	3
Problems of Nuclear Radiation in Environmental Sanitation[a]	3
Stream Sanitation[a]	3
Atmospheric Pollution[a]	3
Ph.D. Degree:	
Physical Chemistry (second course)	3
Nuclear Chemistry	3
Water Supply and Treatment	3
Evaluation of Engineering Data	3
Advanced Public Health Engineering	3
Microbiology of Waste Treatment and Receiving Waters	3
Micrometeorology of Pollutant Dispersion	3
Radiation Effects, Radiation Biology, and Toxicology	4

ADDITIONAL ELECTIVE COURSES (INCOMPLETE)

Radiation Biology	4
Industrial Waste Treatment	3
Air Pollution Sampling and Analysis	3
Air Pollution Control Measures	3
Radiation Chemistry	3
Tracer Chemistry	3
Radiological Safety Engineering	2
Nuclear Engineering Laboratory	3-6
Modern Physics	3
Nuclear Physics	3

[a] Core courses recommended also for specialization in Air Pollution and in Water Supply and Waste Water Disposal.

Theoretical Nuclear Physics	3-6
Laboratory Techniques in Nuclear Physics	1
Nuclear Power Reactors	3
Medical (Radiation) Physics	3
Statistical Methods in Research	3
Design of Experiments	3

APPENDIX II.—RECOMMENDED CORE COURSES FOR MAJOR FIELDS OF CONCENTRATION

WATER SUPPLY AND WASTE WATER DISPOSAL

Mater's Degree:	Credits
The Chemistry of Water Treatment	3
Quantitative Analysis	4
Physical Chemistry	3
Sewage Treatment	3
Problems of Nuclear Radiation in Environmental Sanitation	3
Stream Sanitation	3
Atmospheric Pollution	3
Ph.D. Degree:	
Water Supply and Treatment	3
The Analytical Control of Water Treatment	3
Evaluation of Engineering Data	3
Hydrology	3
Microbiology of Waste Treatment and Receiving Waters	3
Advanced Sanitary Engineering Design	3

AIR POLLUTION CONTROL

Master's Degree:	
Quantitative Analysis	4
Physical Chemistry	3
Problems of Nuclear Radiation in Environmental Sanitation	3
Stream Sanitation	3
Atmospheric Pollution	3
Micrometeorology of Pollutant Dispersion	3
Ph.D. Degree:	
Physical Chemistry (second course)	3
Water Supply and Treatment	3
Evaluation of Engineering Data	3
Advanced Public Health Engineering	3

Advanced Sanitary Engineering Practice	3
Air Pollution Sampling and Analysis	3
Air Pollution Control Measures	3

ADDITIONAL ELECTIVE COURSES AVAILABLE IN EITHER MAJOR

Water Supply and Treatment	0[b]
Sewerage	0[b]
Sewage Treatment	3
Industrial Waste Treatment	3
Sanitary Engineering Laboratory	3
Problems in Sanitation	3
Advanced Public Health Engineering	3
Hydrology	3
Microbiology of Waste Treatment and Receiving Waters	3
Advanced Sanitary Engineering Practice	3-6
Advanced Sanitary Engineering Design	3-6
Air Pollution Sampling and Analysis	3
Micrometeorology of Pollutant Dispersion	3
Air Pollution Control Measures	3
Statistical Methods in Research	3
Design of Experiments	3

[b] Foundation courses required for students who have not had them.

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

POLLUTION OF THE ANDROSCOGGIN RIVER[a]

By E. Sherman Chase,[1] F. ASCE

SYNOPSIS

The Androscoggin River has had a 20 yr record of observations and analyses under a court-appointed monitor. The river has a drainage area of nearly 3,000 sq miles, on which the principal sources of pollution are three large paper and pulp mills.

In 1940 the pollution equivalent of these wastes was about 2,000,000 compared with 100,000 from municipalities. In the summer of 1940 the pollution reduced the dissolved oxygen of the river to zero for a distance of about 100 miles. Offensive odors were prevalent in summer. Fish died.

Legal action brought by the Attorney General resulted eventually in a court decree that required remedial measures. These were storage lagoons for sulfite liquor with controlled discharge, regulated production of sulfite pulp, changes in manufacturing processes, application of $NaNO_3$ under extreme conditions to the pool above the power dam at Lewiston, analyses of the river, and the appointment of a court-appointed administrator to monitor compliance with the decree.

The remedial measures have resulted in successive improvement in river conditions. Nearly complete correction of the odor nuisance has been accom-

Note.—Discussion open until August 1, 1961. To extend the closing date one month, a written request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. SA 2, March, 1961.

[a] Presented at the October 1960 ASCE Convention in Boston, Mass.

[1] Cons., Metcalf & Eddy, Boston, Mass.

plished. The river remains polluted, but it is not the public nuisance it was 20 yr ago. Further reduction of pollution will be brought about when another mill adopts the sulfite process.

INTRODUCTION

No stream in the United States, to the writer's knowledge, has had so long a record of observations and analyses under private auspices as the Androscoggin in Maine. Neither has there been any other stream in which the pollution has been controlled by a court appointed monitor retained by the contributors of the major sources of pollution.

The present paper is a brief review of 20 yr experience with the condition of the river (1940 to 1959 inclusive). This period covers 3 yr prior and 17 yr after control measures were started. Another publication[2] provides details with respect to the characteristics of the Androscoggin and conditions prior to 1949.

ANDROSCOGGIN RIVER

The Androscoggin River, rising at the junction of Maine, New Hampshire, and the province of Quebec, flows in a general southeasterly course approximately 200 miles to tidewater at Brunswick, Me. (Fig. 1). The total drainage area of the river and its tributaries is 3,470 sq miles. There are a few fair-sized municipalities along the river, however, most of the area is sparsely settled. The largest municipal area is Lewiston-Auburn, Me. with a population of 65,000.

A number of water powers have been developed and industries established along its course because of the relatively steep slope of the stream. The principal industries are cotton textiles and pulp and paper manufacturing, the latter predominating. Control of stream flow is regulated from large storages[3] at the headwaters and on certain tributaries by a river master representing, through a separate corporation, the several interests involved. On the main stream, there are a number of power dams. Some of them back up the level of the river nearly to the next upstream dam. The largest of these power reservoirs is formed by the Gulf Island dam just above Lewiston. Other reservoirs occur above Livermore Falls and Rumford, Me., and at Berlin, N. H. These four municipalities are approximately 24 miles, 56 miles, 83 miles, and 135 miles, respectively, above tidewater at Brunswick, Me. The river elevation at Berlin above sea level is approximately 1,000 ft.

The average annual runoff at Rumford is distributed fairly uniformly throughout the year except for the spring months. This uniformity results from regulation of storages previously referred to. In the summer, the discharge at Gulf Island is 2,000 cfs.

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[2] "Pollution of the Androscoggin River by Industrial Wastes and Control Measures Thereof," by E. Sherman Chase, Journal, Boston Soc. of Civ. Engrs., Vol. 36, No. 3, 1949, p. 357.

[3] "Water Power Storage in Maine," by Howard M. Turner, Journal, Boston Soc. of Civ. Engrs., Vol. 36, No. 3, 1949, p. 309.

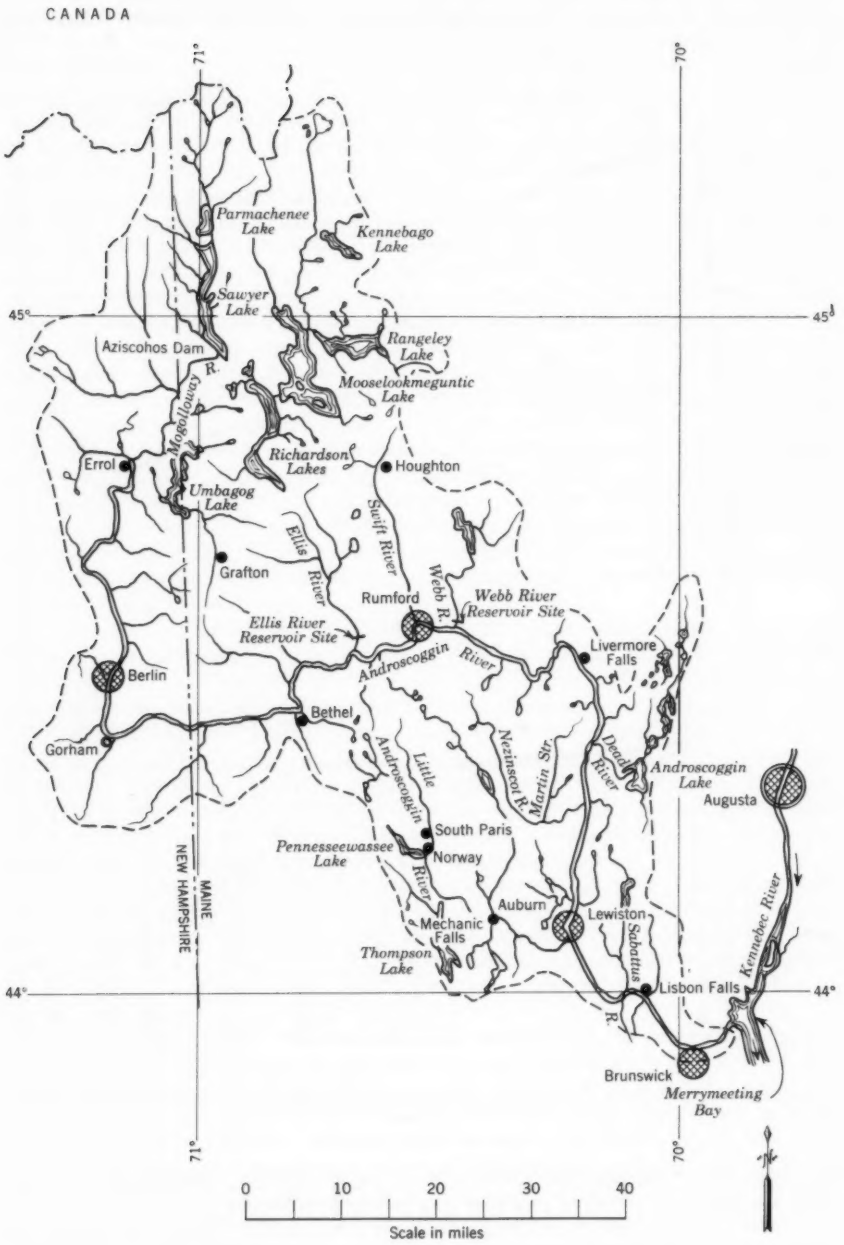

FIG. 1.—ANDROSCOGGIN RIVER DRAINAGE AREA

The stream has a few stretches of rapids below Berlin because of the backing up process of the dams. The relatively smooth flow is a factor in minimizing reaeration. The ponding behind the dams also increases the time

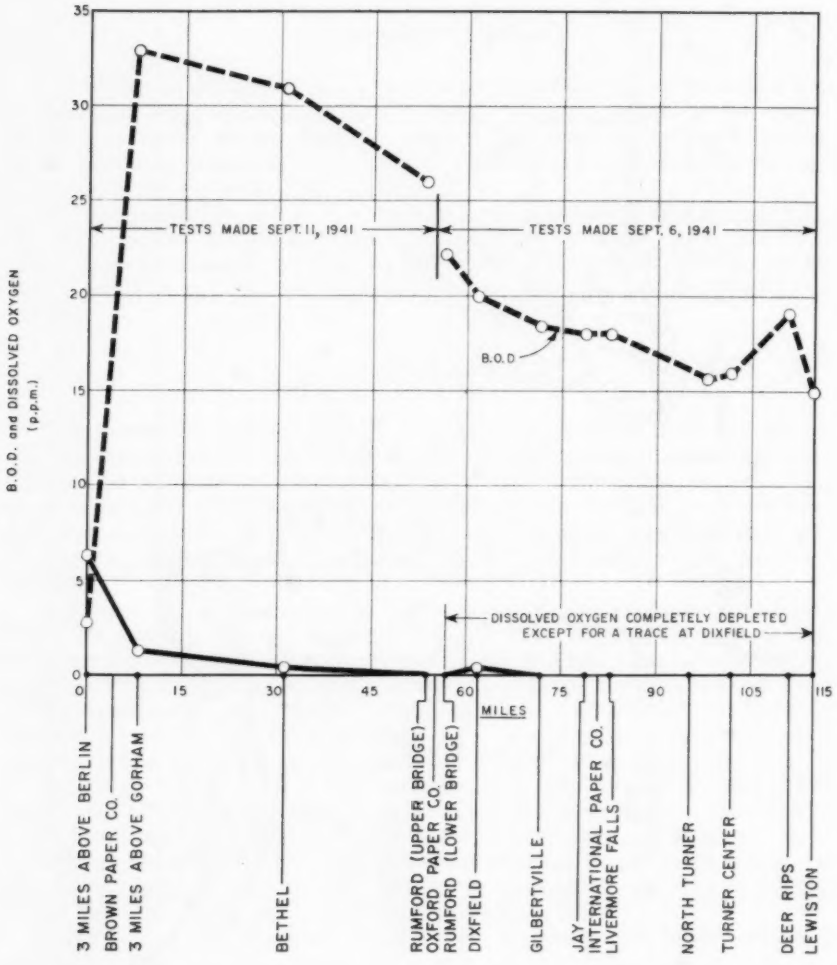

FIG. 2.—OXYGEN CONDITIONS ALONG ANDROSCOGGIN RIVER SEPTEMBER, 1941

of flow and facilitates deposition of suspended matter. These facts are significant when the effect of pollution is under consideration.

Sources of Pollution.—Sewage from about 100,000 people is discharged untreated by the several communities along the river and its major tributaries.

The largest contribution of pollution, however, comes from the pulp and paper mills at Livermore Falls, Rumford, and Berlin, respectively. Of the wastes discharged by the mills, the sulfite digestion liquors are the most potent. In 1941, these were found to approximate 71% of the total pollution load, industrial and municipal, and 74% of the industrial load. The total population equivalent of all industrial pollution was approximately 2,500,000.

Investigations of Pollution and its Effects.—Prior to 1940, the State Board of Health had investigated the condition of the river and the effect of the pollution. The obnoxious odors emanating from the river for many miles along its course were then and subsequently matters of common knowledge. In 1940, engineers were retained to look into the matter.[4] At that time it was found that in the middle of September the stream was devoid or nearly devoid of oxygen for nearly the entire distance from Lewiston to Berlin. In the following year (1941), another investigation was made for the Maine Sanitary Water Board,[5] however, the investigation did not begin until early September (Fig. 2). The river was again found to be in bad condition with no dissolved oxygen from above Rumford to below Lewiston, a distance of 60 miles. At Lewiston, in the center of the city, the prevailing odor of hydrogen sulfide was highly objectionable. The concentration of hydrogen sulfide in the atmosphere was sufficient to discolor paint on houses and to tarnish exposed metals. Coupled with the specific rotten egg odor of hydrogen sulfide was another, equally unpleasant smell, described as "pig-pen" for lack of a more specific term.

In the summer, in addition to the bad odors, the stream carried masses of slimey, ill-smelling, floating sludge at various points along its course. Fish could not survive in the absence of dissolved oxygen and many were killed when reaching the main stream.

Following the submission of a report to the Sanitary Water Board early in 1942, the investigating engineers were retained by the Attorney General to assist in the preparation of proceedings against the pulp and paper mills. During the summer of 1942, a series of river inspections and analyses were conducted. One inspection on August 13th, revealed that the river was devoid of oxygen from Lewiston to Berlin, a distance of about 110 miles. Other inspections, during the months of July, August, and September, showed oxygen conditions nearly as bad. On some occasions, hydrogen sulfide was present as far downstream as Brunswick and floating sludge masses 10 ft wide, or more, were present at certain points of observation.

In 1943, following the start of legal action by the Attorney General against the pulp and paper mills, the mills began a weekly program of sampling and analyses of the river from May through October. This program has been continued to date (1961) and the results obtained have shown progressive improvement in river conditions as successive remedial measures have been taken by the mills.

Measures to Remedy Conditions.—The mills began to correct conditions in 1943 under a stipulation with the Attorney General entered into in December, 1942. The mills were to undertake certain remedial measures and further legal action was to be deferred until after October, 1943 pending the results. This stipulation called for an experimental lagoon for sulfite liquors, weekly

[4] "Investigation of Sanitary Condition of the Androscoggin River," by Metcalf & Eddy, unpublished report to Walter S. Wyman, Pres., Central Main Power Co., 1940.

[5] "Investigation of the Pollution of the Androscoggin River and Remedial Measures," by Metcalf & Eddy, Bulletin No. 1, Maine Sanitary Water Board, 1942.

schedule of river analyses, and restriction of discharge of sulfite liquors. The measures were not sufficiently drastic, and a court decree with more rigorous requirements, with respect to the discharge of sulfite wastes, was issued in January, 1944. These requirements were also inadequate, and the odors from the river in the Lewiston-Auburn area were highly objectionable in the following summer. Conditions were better in the following two yr, but in 1947, the conditions during the summer grew worse and more highly objectionable.

After another court hearing, the January 1944 decree was modified and strengthened, regarding restrictions on the discharge of sulfite liquors, in December, 1947. Under this decree, and in accordance with a recommendation to the court by the writer, Walter A. Lawrance was appointed administrator to regulate those activities of the mills that caused the undue pollution of the river. The modified decree, among other provisions, called for further restriction of the discharge of concentrated sulfite liquors and the construction of a lagoon at Livermore Falls for controlled storage of the sulfite liquors produced there.

One of the criteria for satisfactory control was that the dissolved oxygen in the river at North Turner, at the head of the slack water formed by the Gulf Island dam, should be maintained at not less than 4 ppm.

Although further improvement occurred, unsatisfactory odor conditions recurred in the Lewiston-Auburn area in mid-summer, 1948. A further and final modification of the decree was made in December, 1948, containing quite drastic restrictions with respect to the manufacture of sulfite pulp and the discharge of sulfite liquors. These restrictions were governed by season, flows of river, water temperature, and dissolved oxygen at North Turner. The restrictions, together with the possible application of sodium nitrate were delegated to the control of the court appointed administrator.

Addition of Sodium Nitrate.—The possible addition of sodium nitrate to the Androscoggin to supply needed oxygen was first considered by the writer in 1940, however, the idea was dismissed as involving too great a cost under prevailing conditions. The idea was independently suggested by Lawrance[6] in the summer of 1948 when the atmosphere in the Lewiston-Auburn area was again malodorous (although not as bad as in previous years) in spite of the remedial measures then in effect. Consequently, a full-sized demonstration of the value of sodium nitrate to combat odors was undertaken in August and September, 1948 with 480 tons of nitrate applied between Livermore Falls and the Gulf Island dam. The bulk of the nitrate was added 7 miles upstream of the dam at the Turner Center Bridge.

The control of hydrogen sulfide was sufficiently satisfactory to warrant a continuation of the experiment in the summer of 1949. During the months of July and August 641.5 tons of nitrate were applied of which 561.5 tons were added from a boat to the lower half of the pool formed by the Gulf Island dam. The reasonably successful use of nitrate in the summer of 1948 evidently led to the provision regarding its use in the modified decree of December, 1948.

Since 1948 the application of nitrate to the river water above the Gulf Island dam has been continued every summer. The quantities used per summer have varied from a minimum of 15 tons to a maximum of 957 tons. In all approximately 6,600 tons have been used, representing a total expenditure of

[6] "The Addition of Sodium Nitrate to the Androscoggin River," by W. A. Lawrance, Sewage Works Journal, Vol. 22, No. 6, 1950, p. 820.

about $500,000. Regarding the effectiveness of nitrate, Lawrance writes, "Sodium nitrate has been very effective as an inhibitor of the production of hydrogen sulfide."

The improvements in oxygen conditions at the end of the 20-yr period as compared with those at the beginning of the period is shown by Fig. 3 and yearly comparisons in Fig. 4.

Time of Passage and Temperatures.—Given fixed amounts of pollution discharged per unit of time the most significant factors affecting river conditions are volume of diluting water, time of passage downstream of the increments

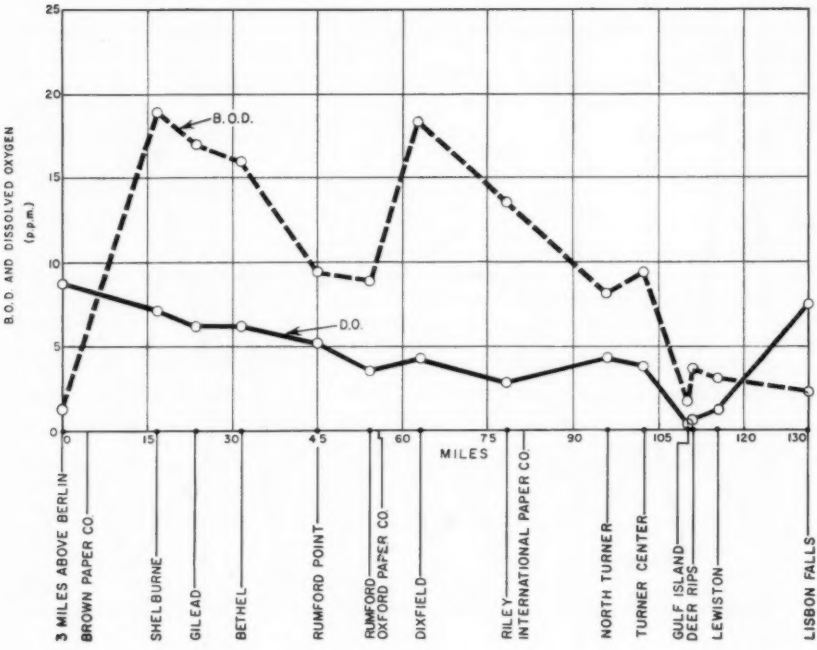

FIG. 3.—OXYGEN CONDITIONS ALONG ANDROSCOGGIN RIVER SEPTEMBER 24, 1959

of pollution and the temperature of the river water. As previously stated, flows are relatively uniform due to regulation of storages for power purposes. Lawrance[7] has presented the data in Table 1 showing the time of passage.

Typical changes in temperature of the river water throughout the late spring, summer, and early fall are given in Table 2.

Remedial Measures Undertaken by Mills.—In the preceding discussion several of the measures taken by the pulp and paper mills have been de-

[7] "Determination of the Time of Passage of Pollution in the Androscoggin River and Pond," by W. A. Lawrance, Sewage Works Journal, Vol. 20, No. 5, September, 1948, p. 881.

scribed. Further reduction in pollution has been brought about by the partial abandonment of the sulfite process by the mill at Berlin and by its construction of lagoons for controlled storage of those sulfite liquors continuing to be produced. This lagoon system was badly damaged by heavy rains and runoff during the September, 1954 hurricane but was repaired and has been in use during the summers from 1955 to 1960.

The decrease in the discharge of sulfite liquors effected by this action is indicated by the fact that in September, 1941 the mill at Berlin was discharging liquor from the production of about 1,200 tons of sulfite pulp per week,

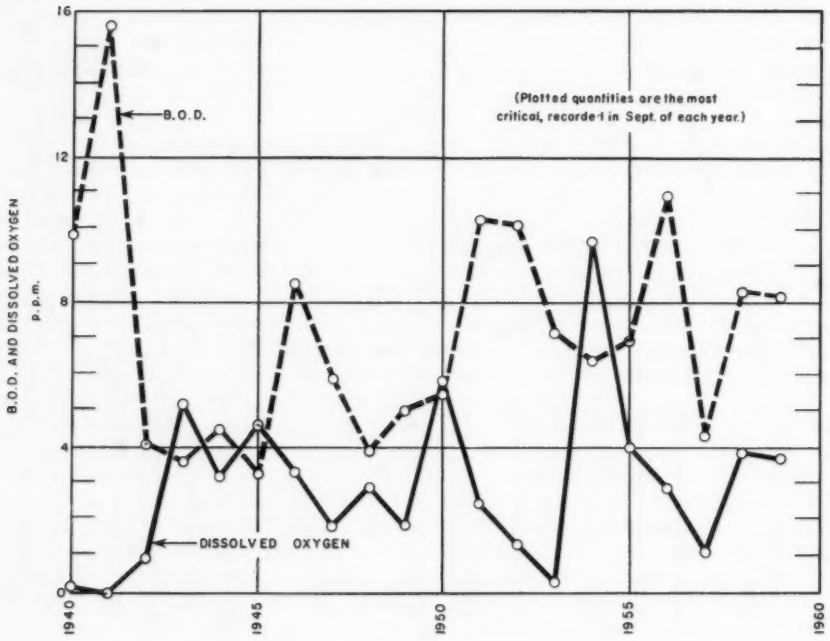

FIG. 4.—CHRONOLOGICAL COMPARISON OF B.O.D. AND DISSOLVED OXYGEN AT TURNER CENTER

whereas in September, 1959 the corresponding production from which wastes were discharged was about 365 tons.

Although an experimental lagoon was built below the mills in Rumford, the seepage through the banks was excessive and the scheme was abandoned. However, the mill at Livermore Falls complied with the decree of 1947 and built a 22,000,000 gal lagoon. All three mills have complied with the provisions of the latest decree (December, 1948) and the post of administrator has been maintained, a post unique in the writer's experience.

The mill at Rumford plans to convert from the sulfite to the sulfate process and is building a new kraft mill. This mill is expected to be completed

sometime in 1961. When this is accomplished the total quantity of sulfite liquors from all three paper mills will be greatly reduced during the critical summer months. The reduction in industrial pollution may be so great as to result in municipal sewage being the major source of pollution.

Odor Observations at Lewiston-Auburn.—The administrator has made daily observations in the Lewiston-Auburn area during the critical summer periods from 1943 to 1960.

TABLE 1.—TIME OF PASSAGE OF POLLUTION IN THE ANDROSCOGGIN RIVER AND POND - 1945 FROM BERLIN, N. H.[a]

Location (1)	Time, in days (2)	Miles (3)	Average flow, in cfs (4)
Berlin, N. H.	0	0	1,790
Virginia Br., Rumford, Me.	2.5	53	2,080
Chisholm, Me.	5	80	. . .
N. Turner Br., Me.	5.5	93	. . .
Turner Center Br., Me.	7.5	100	. . .
Gulf Island Dam, Me.	15.0	107	2,100
Lewiston, Me.	16.25	112	. . .

[a] Times of passage computed from analytical data.

TABLE 2.—RIVER TEMPERATURES AT GULF ISLAND DAM, 1949

Date		Temperature, in degrees centigrade	Date		Temperature, in degrees centigrade
May	7	120°C.	Aug.	6	24.4°C.
	14	16.5		13	23.2
	21	17.0		20	25.2
	28	21.0		27	22.5
June	4	20.7	Sept.	3	22.8
	11	20.7		10	22.5
	18	14.0		17	19.4
	25	18.0		24	17.5
July	2	18.2	Oct.	1	19.0
	9	22.0		8	17.0
	16	23.3		15	15.0
	23	24.9			
	30	25.8			

Table 3 shows a comparison of the prevalence of objectionable odors from the river in the Lewiston-Auburn area from 1943 to 1949. This comparison is indicated by the average weekly number (called the odor factor) of observation stations at which offensive odors of distinct or greater intensity were observed during the four consecutive summer months of maximum odors. It should be noted that the worst possible odor factor would be 56. Note also that only odors classified as "offensive" and "distinct" are used in establishing

the "odor factor." Odors of less intensity and of other than offensive character have occurred in summers in which the odor factor is reported as zero in Table 3.

Table 3 shows that from the standpoint of odor control the carrying out of the provisions of the decree by the mills has resulted in almost complete correction of the odor conditions that brought about the legal action. The river remains a polluted stream but not a gross public nuisance.

Until 1959 the objectionable odors have varied in occurrence and intensity. In general, from 1948 to 1958 progressive improvement in odor conditions occurred as shown by Table 3. No objectionable odors have been noted in the Lewiston-Auburn area in 1959 and 1960.

TABLE 3.—ODOR FACTOR, LEWISTON-AUBURN

Year (1)	Factor (2)	Year (3)	Factor (4)
1943	9	1951	0.3
1944	23	1952	0.2
1945	11	1953	0
1946	14	1954	0
1947	20	1955	0
1948	2	1956	0
1949	0.2	1957	0.4
1950	0.2	1958	0
		1959	

Conditions in 1960.—During the middle of September, 1960 the writer made a personal inspection of the river from Lewiston to above Berlin. At no point were objectionable odors noted as coming from the stream. The operating superintendent of the power station at the Gulf Island dam stated there had been no odors during the past summer and that no accumulation of floating sludge had occurred above the dam.

At the Turner Center bridge, across the pool formed by the dam, gas bubbles and small pieces of floating sludge were noted. In 1940, 1941 and 1942 much sludge and gas ebullitions took place at this point far exceeding the amounts noted in September, 1960. A marked contrast also occurred at the bridge just above Rumford. In 1940 and the years immediately following continuous processions of floating sludge masses, 1 ft across were common phenomena. In September, 1960 no floating sludge at all was noticed, a strikingly different condition than existed at the beginning of the 20-yr period.

The present paper has been limited to a general outline of what has occurred in the past 20 yr. A vast amount of basic research[8,9,10] has been carried out and much data collected.

CONCLUSIONS

The experience with the Androscoggin River over the 20-yr period has demonstrated:

1. The relatively long time to effect correction of industrial pollution irrespective of the legal measures invoked.
2. The fact that the occurrence of extremely objectionable odors affected a considerable number of people was the prime motivation for legal action.
3. The feasibility of controlled discharge of concentrated sulfite liquors.
4. The marked decrease in concentration of pollution by the reduction in discharge of such liquors.
5. The value of sodium nitrate for providing oxygen with resultant control of odors in the critical Lewiston-Auburn area.
6. The avoidance of odor formation so long as any available oxygen was present in the river water.
7. The practicability of the unique method of monitoring the sanitary condition of the stream by a court appointed administrator retained by the offending mills.

ACKNOWLEDGMENTS

The writer expresses his appreciation to the research directors and chemists of the pulp and paper mills for supplying him with the data relative to the condition of the river and is particularly indebted to Lawrance for information he supplied.

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8 "Polarographic Determination of Nitrate," by W. A. Lawrance and R. M. Briggs, Analytical Chemistry, Vol. 25, 1953, p. 965.

9 "The Microbial Oxidation of Pure Carbohydrate in the Presence of Calcium Lignosulphonate," by W. A. Lawrance and H. M. Fukin, Tappi, Vol. 40, 1957, p. 342.

10 "The Microbial Oxidation of Cellbiose, Butyric and Lastic Acids in the Presence of Calcium Lignosulphonate," by W. A. Lawrance and William Sakamoto, Tappi, Vol. 42, 1959, p. 93.

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

REMOVAL OF FLOATABLES FROM DIGESTED SLUDGE

By R. J. Theroux,[1] F. ASCE, C. H. Lawrance,[2] M. ASCE,
and N. B. Hume,[3] F. ASCE

SYNOPSIS

In connection with the proposed discharge of sludge from Los Angeles Hyperion Treatment Plant, it was realized that if proper precautions were not taken, some problems might develop in respect to the appearance of rubber particles on the ocean surface. Accordingly a research program was instituted to determine the most effective and economical means of insuring removal of floatable fractions before discharge. This paper describes certain laboratory and pilot plant studies and other investigations leading to the final design of a sludge treatment process intended to prevent problems of this nature.

INTRODUCTION

For several years the Hyperion Sewage Treatment Plant, Los Angeles, Calif. disposed of sludge by producing fertilizer for sale. Primary and waste high rate activated sludge was digested, elutriated, vacuum filtered, dried, and sold in bulk or bagged form. Unforeseen difficulties arose in the processing of the sludge and the marketing of the fertilizer produced. It was

Note.—Discussion open until August 1, 1961. To extend the closing date one month, a writttn request must be filed with the Executive Secretary, ASCE. This paper is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. SA 2, March, 1961.

[1] Exec. Asst., Koebig and Koebig, Cons. Engrs., Los Angeles, Calif., formerly Project Engr., Hyperion Engrs., Los Angeles, Calif.

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[3] Dir. of Bur. of Sanitation, Los Angeles, Calif.

therefore decided to abandon fertilizer production, and to dispose of digested sludge to the deep waters of Santa Monica Bay through a 7-mile long submarine outfall.

The sludge outfall, subsequently designed by the city's consultants, has been constructed and placed into operation. Pertinent features of the design and operation have been described.[4] Analysis of the relative economics of fertilizer production and ocean disposal of digested sludge is also available.[5]

The specific gravity of the digested sludge was determined by laboratory measurement to be 1.011 at a temperature of approximately 70 F. Although this was less than the specific gravity of the sea water into which the sludge was to be discharged, studies showed that initial dilution on injection would be sufficiently high to create a submerged field with a specific gravity greater

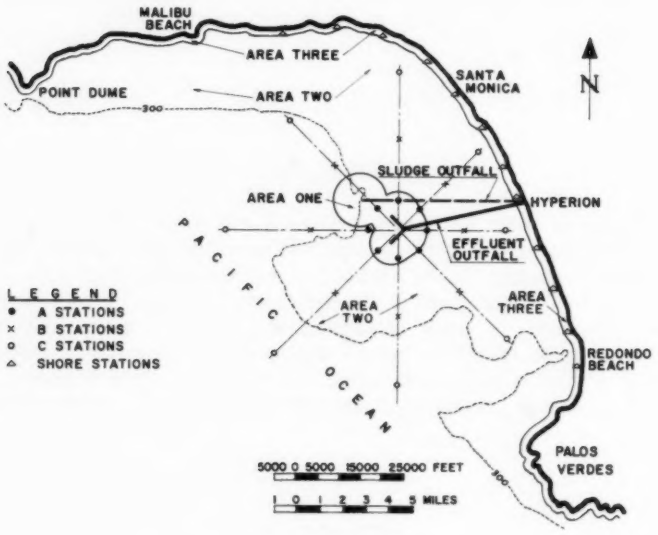


FIG. 1.—RECEIVING WATERS POLLUTION CONTROL STANDARDS FOR HYPERION SLUDGE AND EFFLUENT OCEAN OUTFALL DISCHARGES

than the surface water of the bay. Thus, the sludge as a whole would remain entirely submerged and the sedimentation of much of the sludge would take place within a relatively short distance from the point of discharge.

It was recognized, however, that sludge, even digested sludge, is heterogeneous and contains a variety of fractions making up the overall specific gravity of 1.011, some of which might be expected to rise to the surface of the ocean. The California Water Pollution Control Board had prescribed ef-

[4] "Operation of a 7-Mile Digested Sludge Outfall," by N. B. Hume, R. D. Bargman, C. G. Gunnerson, and C. E. Imel, Proceedings, ASCE, Vol. 86, No. SA 2, March, 1960.

[5] Discussion by C. H. Lawrance and D. A. Miller of "Operation of a 7-Mile Digested Sludge Outfall," by N. B. Hume, et. al., Proceedings, ASCE, Vol. 86, No. SA 2, March, 1960.

fluent requirements for the proposed discharge as depicted in Table 1 for the areas indicated in Fig. 1. Although there were no bacterial standards prescribed for Area 1, which included all waters within 5,000 ft of the nearest outlets designed to discharge either effluent from the 5-mile outfall or digested sludge from the 7-mile outfall, there were to be no floating or suspended solids recognizable by eye as fecal matter, garbage, or rubber goods. There was also no noxious offensive odor, gases or fumes of sewage origin in the receiving waters of Area 1. These requirements also applied to Area 2, constituting the remaining offshore waters, and Area 3, constituting the littoral waters. The floatable material considered as potential trouble makers in the ocean included such items as hair, grease, cellophane particles, filter tips, and particularly, fragments or whole specimens of rubber goods. Many of

TABLE 1.—MONITORING PROGRAM STANDARDS REQUIRED[a]

Item	Sampling Stations			
	A	B	C	Shore
S. M. Bay Area	1	2	2	3
Range of Distances from Origin Feet	∠5000 to ∠ 7500	13000 to 22000	23000 to 42000	1500 ft from hwl
Coliform Organisms mpn per Milliliter	No Limit	Geometric of B and C	Mean ∠100	10
Dissolved Oxygen	≦ 6 ppm	—	—	—
Grease, Average	≦ 2 ppm	—	—	None
Floating or Suspended Sewage Solids	None	None	None	None Below hwl
Transparency, feet by Secchi Disk	No Limit	≧ 20	≧ 20	—
Organic Content of Bottom Samples	No Limit	≦ 50%	≦ 50%	—
Annual Increase of	No Limit	≦ 3%	≦ 3%	—

[a] By May 2, 1956 order of the State Water Pollution Control Board.

these fractions undergo relatively little decomposition in the digestion process.

The position of Los Angeles with respect to the previously mentioned requirements is clearly set forth in the following "Whereas" which is a portion of a resolution adopted by the Los Angeles City Council:

> "WHEREAS, it is the policy of the City of Los Angeles to provide and maintain facilities for the treatment and disposal of sewage which shall be, at all times, adequate in capacity, and adequate for the protection of the public health and the public interests in this and neighboring communities including maintenance of the beaches and coastal waters in an attractive condition suitable for recreational and other beneficial uses equal to or better than the conditions specified by the State agencies having control over the subject matter;"

With this policy in mind, design progressed on the new hyperion facilities with due consideration being given to the possibility of a "floatables" problem.

During the design of the sludge outfall, investigations were not conclusive regarding the amount, importance, and best treatment method for floatable solids which might appear in the ocean as a result of the digested sludge discharge, and therefore, the design of sludge conditioning facilities was held in abeyance pending the outcome of the actual plant scale discharge of digested sludge.

APPEARANCE OF FLOATABLES IN OCEAN

Since the inception of operation of the sludge outfall, floatables have not been of such nature or concentration as to be commented on. As far as can be determined they have not been noted by lay observers despite the fact that the bay is now a popular sports fishing and recreational area. Floatables in minor amounts have been observed by trained personnel and are a consequence of the city's critical appraisal of the problem.

Floatables from the sludge discharge did not appear in the first few weeks of operation of the new outfall. The discharge of approximately 75% of the daily load of digested sludge solids, mostly in the form of elutriation tank overflow and secondary digester supernatant, had remained entirely submerged in the ocean. However, when elutriation was suspended and 100% of the digested sludge and supernatant was discharged through the sludge outfall using, in part, sludge from stirred, normally quiescent, secondary digesters, floatables made their first appearance on the surface of the ocean. They were in the form of fields of small fragments of rubber goods not much more than 1/4 in. in diameter, concentrated in the top 10 ft of the surface waters, usually beginning within a few thousand feet of the outlet and extending for about 2 miles to 5 miles downcurrent. Some other sludge detritus, notably cellophane, was also present. Hair did not show at all and grease particles were rarely evident. The fields were relatively narrow and patchy and the floatables were normally not concentrated. They tended to remain a considerable distance offshore due to ocean convergences. On infrequent occasions, the city's trained personnel have found floatables on the beaches themselves.

PRELIMINARY LABORATORY EXPERIMENTS

Experiments of a qualitative nature were undertaken in the plant laboratory to learn more of the process of separation of floatable fractions of digested sludge, which the ocean was apparently accomplishing, and to point the way towards feasible methods of removal of such floatables prior to ocean discharge. The experiments primarily involved introduction of 200 ml of pretreated digested sludge into the bottom of a graduate containing 900 ml of sea water and noting the settling properties of the sludge, and the separating out or failure to separate out of the rubber and other light particles. Within these experiments, the most promising methods of pretreatment of the digested sludge appeared to be the following:

1.—Elutriation with sea water;
2.—dilution with plant effluent;
3.—dilution with sea water;

4.—elutriation followed by dilution, both with plant effluent; and
5.—elutriation followed by dilution, both with salt water.

Where salt water elutriation was used as the treatment prior to submarine injection, there was a complete and fairly rapid settling out of all fractions of the sludge. In all other cases there was a classification of fractions to varying degrees. The rubber and some other particles rose to the surface and the remainder settled to the bottom of the graduate.

In addition to these elutriation and dilution studies, vacuum floatation was tried experimentally as a means of pretreatment of the digested sludge. It was unsuccessful, however, in removing significant amounts of the rubber material. The salt water elutriation process appeared most promising of all, but because of the substantial capital outlay that would be required to con-

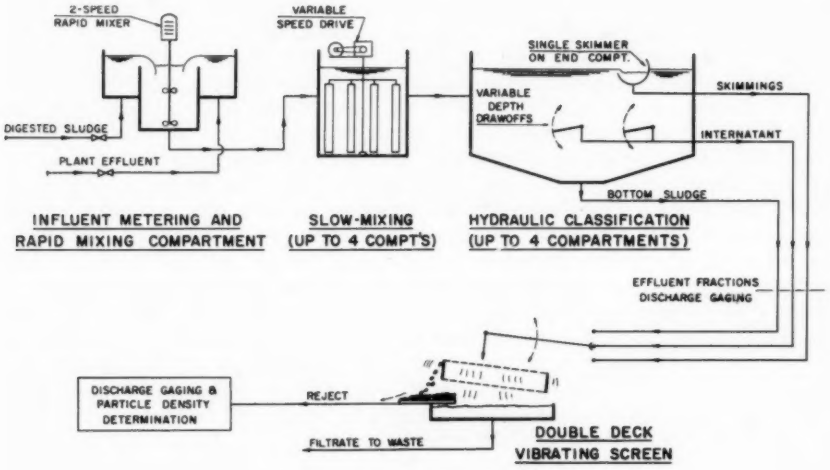


FIG. 2.—SCHEMATIC DIAGRAM OF EXPERIMENTAL HYDRAULIC CLASSIFICATION TANK FOR TREATMENT OF HYPERION DIGESTED SLUDGE PRIOR TO OCEAN DISPOSAL

struct a salt water elutriation pilot plant and, more important, the eventual cost of a prototype plant, this method was set aside in favor of more economically feasible methods of pretreatment.

HYDRAULIC CLASSIFICATION TANK

Fresh water elutriation, utilizing plant effluent, was selected as a subject of pilot plant study. This elutriation would incorporate certain features not offered by the existing elutriation tank, including high horsepower rapid mixing, slow-stirring, and intermediate depth effluent drawoff points in addition to the usual surface launders and bottom sludge drawoffs. The laboratory experiments had indicated the desirability of all of these features in sludge pretreatment prior to ocean disposal.

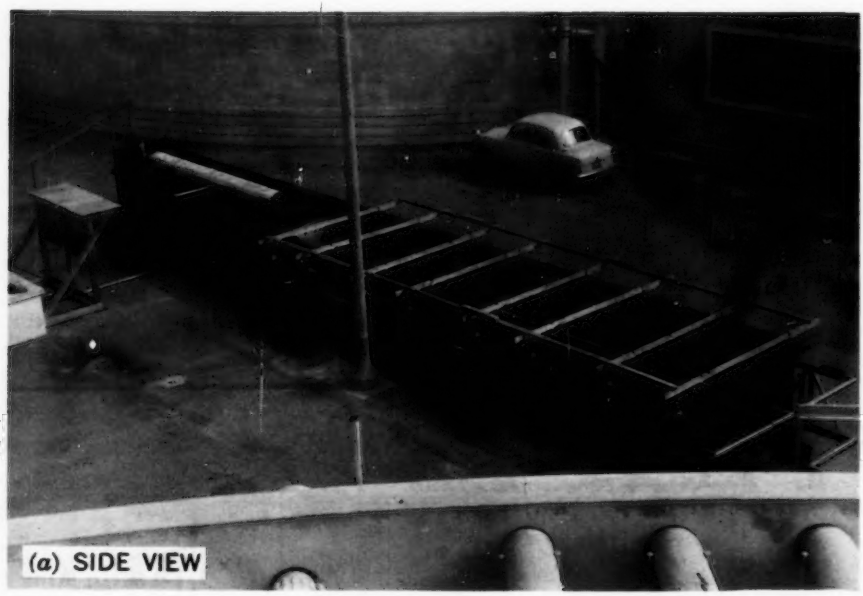
The fresh water elutriation would accomplish hydraulic classification as an intermediate process in sludge pretreatment designed to remove all or nearly all of the floatable solids identifiable as being of sewage origin, and rejecting the fractions of the sludge whose submarine discharge would result in no undesirable condition in the receiving waters. The floatable fractions so removed would then be subjected to additional treatment as necessary prior to ultimate disposal. In any event, the volumes of floatables and extraneous material to be so processed would have been drastically reduced from the original volume of the digested sludge due to the classification tank operation. The discontinuance of the fertilizer project made potentially available for sludge processing one of the three existing digested sludge elutriation tanks, the other two being available for diluting the sludge prior to pumping it out through the submarine outfall. This tank was presumed available for the future modification into a hydraulic classification unit if experimental work found it desirable. The pilot-plant tank design, therefore, incorporated certain aspects somewhat similar to the existing elutriation tank.

The pilot plant classification tank is depicted schematically in Fig. 2. It consisted of parallel metering compartments for digested sludge and diluting plant effluent, respectively. It also included a rapid mixing compartment with a two-speed double propeller type rapid mixer, four slow mixing compartments with picket-fence type stirrers usable either in series or parallel or individually, and four hydraulic classification compartments in series. The classification compartments were each provided with a sludge hopper and variable depth intermediate drawoff pipes for removal of so-called internatant flow. A portable skimmer trough was provided and was located on the farthest downstream classification compartment selected for use. Fig. 3 further illustrates the construction. Fig. 3(a) shows the tank before use. Note internatant and sludge drawoff pipes on the side. Fig. 3(b) shows the plant in operation. Note mixers in foreground and vibrating screen in left background. The design provided the opportunity for operation over a wide range of dilution ratios and mixing and sedimentation parameters as are listed in Table 2.

From the pilot plant experiments it was hoped to establish relationships among the preceding parameters and removal efficiency of rubber particles from the digested sludge that would ultimately lead to the most optimum prototype design from the standpoint of performance and economy.

A total of twenty-six runs were made utilizing the hydraulic classification tank and primarily aimed at determining the efficiency of removal of rubber particles and cellophane particles for various combinations of sludge dilution, mixing horsepower, overflow rate in sedimentation, proportion of flow drawn off in skimmings, internatant, bottom sludge, and other pertinent parameters. A double deck vibrating screen was used to measure the concentration of rubber and cellophane particles in the incoming sludge to the classification tank and in the fractions of effluent flows represented by skimmings, internatant flow, and tank sludge compartment flow.

The top screen was 12-mesh and the bottom screen was 24-mesh. These two screens intercepted the entire content of rubber and cellophane particles in addition to considerable extraneous materials. Rates of flow of the rubber and cellophane particles were established and used in the evaluation. Physical counting of individual particles from samples of the screen reject was necessary to establish particle concentrations. Digested sludge from one of the primary digestion tanks was normally used. Distribution of sludge constituents



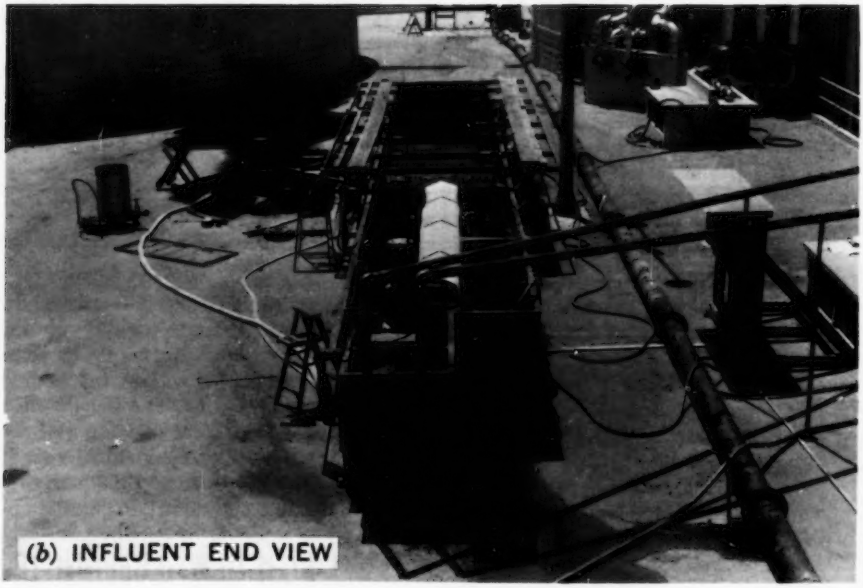


FIG. 3

within this typical tank showed wide dispersion of humus material, vegetable matter, cellophane, hair, and some grease throughout the depth of the tank.

Rubber material was confined exclusively, as far as the sampling procedure was able to demonstrate, to the top 2 ft or 3 ft of the depth of the liquid within the digester. It was necessary to draw from this particular depth interval in order to be assured of including rubber particles in the influent sludge. This scum level also contained fairly high concentrations of hair, cellophane, cigarette filter tips, and undigested grease.

The fresh water elutriation process as demonstrated by the pilot plant hydraulic classification tank was successful in separating and floating off the great bulk of the rubber material from the digested sludge. The removal of cellophane particles was only partial. The heterogeneity of the sludge limited the number of experimental runs that could be accomplished and rendered it difficult to obtain conclusive data for establishing the desired design parameters of hydraulic classification. However, it was possible to determine how much volume of potential vibrator screenings could be anticipated from any of the fractions of effluent, such as the skimmings, depending on the portion of the total effluent flow represented by such a fraction. Fig. 4 illustrates this relationship.

TABLE 2.—SCOPE OF HYDRAULIC CLASSIFICATION

	Metering Compartments 2 each				Flash Mixing Compartment 1			
Valve of Parameter (1)	Dilution, in volumes dilutent per volume sludge (2)	Sludge flow, in gpm (3)	Dilutent flow, in gpm (4)	Total flow, in gpm (5)	Volume, in cu ft (6)	Detention, in min (7)	Propeller peripheral Speed, in fps (8)	Power Dissipation, in ft-lb per sec cu ft (9)
Minimum	2	2	8	10	8.9	0.67	12	7.5
Intermediate[a]	3	15	45	60	15.8	2.5	24	19
Maximum	5	33	80	140	27	20.2	30	45

[a] Additional intermediate values were also studied.

There did not appear to be any conclusive relationship of dilution ratio of plant effluent to digested sludge for obtaining the maximum removal of rubber particles. There did appear to be a worsening of the usual near-100% removal when the dilution ratio increased to approximately 4.5. Similarly there appeared to be a worsening of the usually complete removal of rubber particles in the skimmings when the application rate of energy to the diluted sludge by rapid mixing, slow mixing, and weir fall combined, increased beyond about 10^{-3} hp per gal per min.

Because of time limitations, it was intended that it would be necessary to vary more than one parameter in many runs and to use a regression analysis

for the establishment of relationships among these various parameters. This procedure would be utilized rather than the more time-consuming procedure of holding all variables constant except for the one under direct study. When approximately 70% of the runs had been completed, the data obtained up to that point were subjected to a first order regression analysis by a computer so as to demonstrate the presence of any linear correlation between any two variables. Relatively few valid correlations were demonstrated by this analysis, probably because the data were insufficient. The analysis did support some generalizations which would normally be expected in the behavior of the classification tank and also indicated that improved removal of rubber particles would be realized with a decreased proportion of the effluent flow from the bottom sludge compartments of the tank.

In the subsequent 30% of the experimental runs the proportion of skimmings flow of the total tank effluent was increased to a maximum and the proportion

TANK PILOT PLANT EXPERIMENTS

each	Slow Mixing Compartment 4 each				Sedimentation Compartment 4 each			
Power Dissipation, in hp per gpm (10)	Total Volume, in gallons (11)	Detention, in min (12)	Power Dissipation, in ft lb per sec per cu ft (13)	Power Dissipation, in hp per gpm (14)	Total Volume, in gallons (15)	Detention, in min (16)	Overflow Rate, in g per day per sq ft (17)	Horizontal Velocity, in fpm (18)
0.002	420	3.0	0.003	Negligible	556	12	62	0.09
0.015	840	14	0.007	0.0002	1986	35	740	0.55
0.1	1680	40	0.12	0.002	3972	397	3450	1.26

of bottom sludge flow decreased to a minimum in hopes of effecting better removal of both rubber and cellophane. In addition, the number of internatant drawoff pipes used was increased in order to decrease the inlet velocity and hence decrease the amount of screenings discharged through the internatant effluent. These additional runs did not produce sufficient additional evidence to define the relationships among the various design parameters sought. The twenty-six experimental runs did demonstrate that except for three occasions the removal of rubber was at least 70% complete.

Although the quantitative data yielded by the runs were relatively meager, considerable qualitative information was obtained by the operation of the pilot plant hydraulic classification tank. For example, it was generally observed that the sludge taken from the bottom compartments of the tank consisted largely of humus material, cellophane, vegetable matter, and some hair, while the materials skimmed from the top of the tank was meager in humus but exceptionally high in hair, cellophane, filter tips, and rubber goods.

During the course of the pilot plant experiments, some additional laboratory tests with injection of digested sludge and fractions into sea water were conducted. Among the observations made were the following:

1. Humus-like muck taken from the bottom sludge compartments of the classification tank and injected into the bottom of an experimental laboratory graduate would remain on the bottom if the graduate contained fresh water,

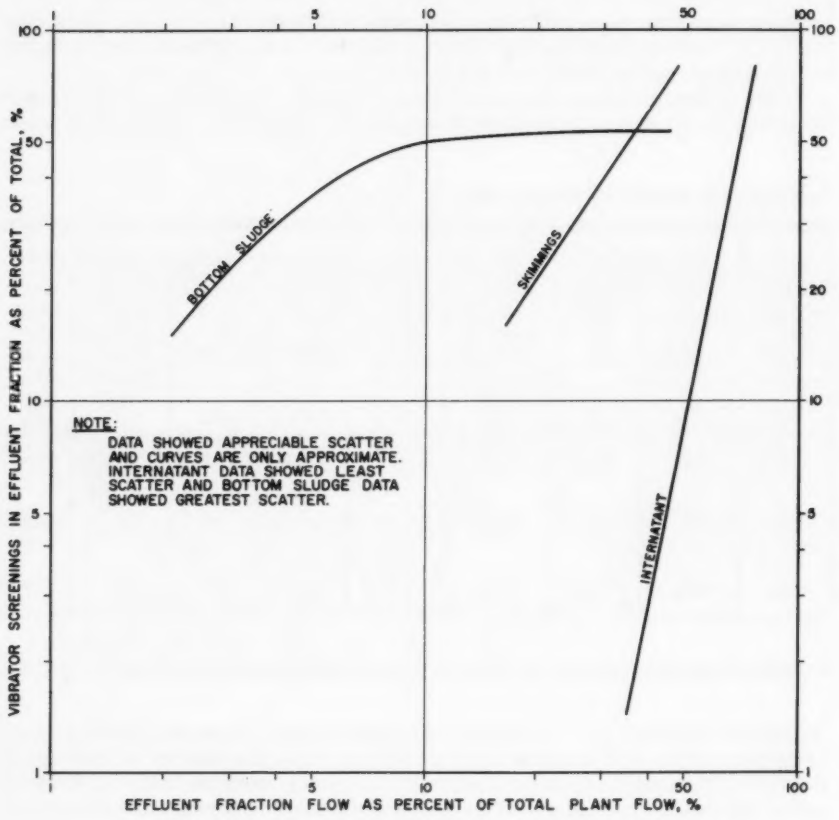

VIBRATOR SCREENINGS IN EFFLUENT FRACTION AS PERCENT OF TOTAL, %
EFFLUENT FRACTION FLOW AS PERCENT OF TOTAL PLANT FLOW, %
1
5
10
50
100
20
BOTTOM SLUDGE
SKIMMINGS
INTERNATANT
NOTE:
DATA SHOWED APPRECIABLE SCATTER AND CURVES ARE ONLY APPROXIMATE. INTERNATANT DATA SHOWED LEAST SCATTER AND BOTTOM SLUDGE DATA SHOWED GREATEST SCATTER.

FIG. 4.—APPROXIMATE DISTRIBUTION OF VIBRATOR SCREENINGS IN EFFLUENT FRACTIONS FROM HYDRAULIC CLASSIFICATION TANK

but would rise to the surface and then begin to settle if the graduate contained salt water. If the muck sample were first degasified under a partial vacuum and then injected into sea water, the material would disperse rapidly but then settle quickly.

2. When skimmings from the classification tank caught on the vibrating screens and containing rubber particles, hair, vegetable matter, cellophane,

filter tips, and small amounts of humus were injected into fresh water, all except the fine material stayed on the bottom.

The finding that hydraulic classification did not always remove 100% of the rubber particles indicated that a more positive method of separation of these objectionable constituents should be used.

SCREENING OF DIGESTED SLUDGE

A pilot plant was set up to test the effectiveness of screens for removal of rubber particles from wet digested sludge. Fig. 5 depicts this layout. The pilot plant consisted of an elevated weirbox arranged to discharge a measured amount of wet digested sludge to either of two test screens, with a measuring point for the filtrate passing through either screen.

FIG. 5.—SCREENING OF DIGESTED SLUDGE

Types of screens tested included a circular vibrating screen, a rectangular vibrating screen, and a concave stationary screen of wedge bars. Preliminary tests with the circular vibrating screen indicated that it was not suitable for digested sludge, so efforts to investigate it further were abandoned.

The rectangular vibrating test screen was of the type which uses a motor-driven eccentric flywheel to impart a forward and backward and up and down motion. The screen was a 14 in.-by-36 in. size and was used in a horizontal position. Screen cloths of both 12 mesh and 7 mesh, with about 45% open area, were used in the experiment. This type of screen is shown on Fig. 6.

In the concave stationary screen the liquid to be screened is discharged at the top of a concave surface (Fig. 7). This surface is actually a series of horizontal steel strands spaced a specified distance apart. As the fluid tumbles down the surface, the water leaks through the steel strands as filtrate, while the reject material continues down the upper surface of the screen. The test screen of this type was 12 in-by-30 in. Strand spacings of 8 per in. and 5 per in. were used. However, the 5 per in. spacing proved to be so coarse

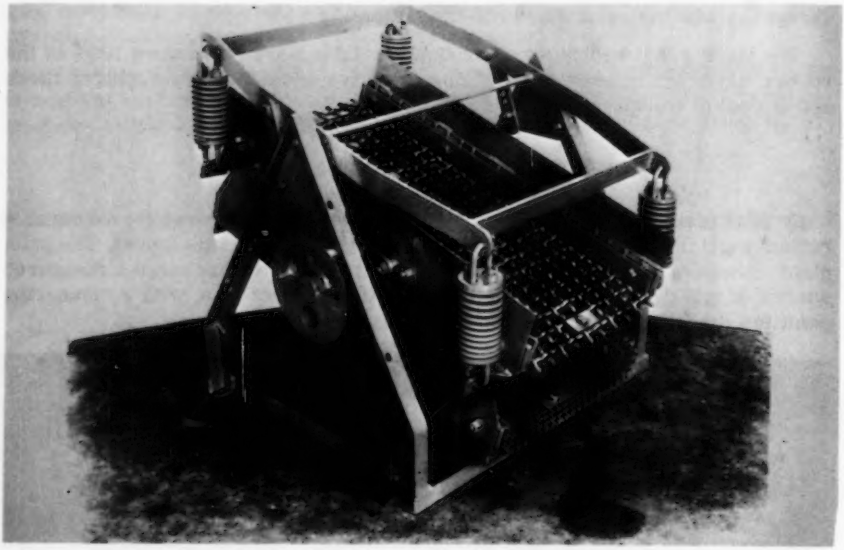


FIG. 6.—RECTANGULAR VIBRATING SCREEN

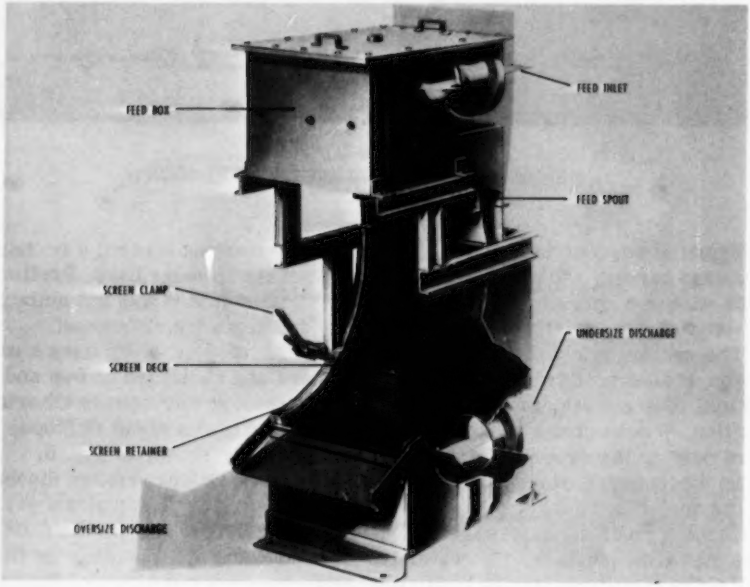


FIG. 7.—CONCAVE SCREEN

that rubber particles would pass through it, so all of the measured testing made use of the 8 per in. spacing.

Digested sludge was obtained from different levels of both primary and secondary digesters. Total solids were determined for the incoming digested sludge being fed to the screens, and for the screen filtrate and reject. The typical sludge being fed to the screens was approximately 4% total solids.

It was found that the 7 mesh and 12 mesh screens on the rectangular vibrating and the 8 to the inch spacing on the concave, stationary screen were completely effective in removing identifiable rubber from the digested sludge. The most important parameter that remains to be determined was the appropriate rate of application of sludge per square foot of each type of screen so that the reject material would be reduced to handleable proportions. It was anticipated that the reject would be ground in a modified disintegrator and sent back to certain of the eighteen existing digesters at Hyperion for long-time digestion. This made it desirable to reduce the reject to as small a volume as possible, commensurate with still being able to grind, pump, and digest the reject.

The screening tests are reported in graphical form in Figs. 8 and 9. It will be noted that the 12 mesh rectangular vibrating screen and the 8-to-the-inch concave stationary screen would generally pass about 60% of the applied sludge as filtrate at a rate of 20 gpm per sq ft. At the same flow rate for the 7 mesh rectangular vibrating screen, over 80% of the applied sludge passed through the screen as filtrate. These rates were variable, especially when portions of the scum blanket were drawn from the digesters. The screening tests indicated that application rates of less than 20 gpm per sq ft did not cause consistently smaller proportions of screen reject. Because of the higher loading rates obtained, the 7 mesh vibrating screen was clearly superior to the other screens tested.

Considerable attention was given to the concave stationary screen because it uses no moving parts, which would probably be an advantage from the operation and maintenance standpoint. The screen proved to be self-cleaning in the sludge tests, although the screen surface can be readily reversed to allow back-flushing of the steel strands if necessary. However, this apparent maintenance advantage for the concave stationary is overshadowed by the ability of the rectangular vibrating screen to pass much more of the applied sludge as filtrate. This is significant because the final disposal point for the digested sludge is the ocean, and the only object of screening is to remove the rubber while removing the least possible amount of other sludge solids. Any material rejected by the screens and returned to the digesters would tend to build up a recirculating load between screen and digester.

The concentrations of total dry solids in the screening reject and filtrate, respectively, were not found to differ greatly from that of the digested sludge applied to the screens. With an incoming sludge of 4% total solids, the reject was less than 5% solids and the filtrate over 3% solids. This is favorable because it shows that it was not necessary to strip the sludge of all its solids in order to separate the rubber. It might also indicate that screens could be used in series, with the reject material continuing to contain all of the rubber, not getting much denser, but becoming smaller in volume with each pass.

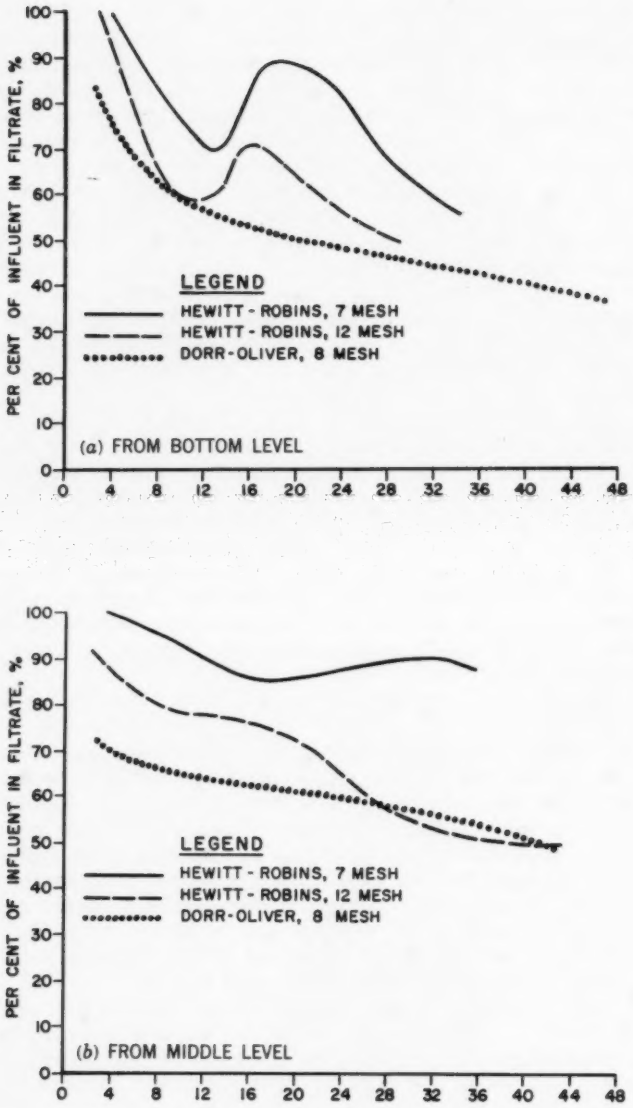


FIG. 8(a),(b).—COMPOSITE CURVES OF FINE SCREENING PERFORMANCE FOR HYPERION DIGESTED SLUDGE FROM VARIOUS LEVELS

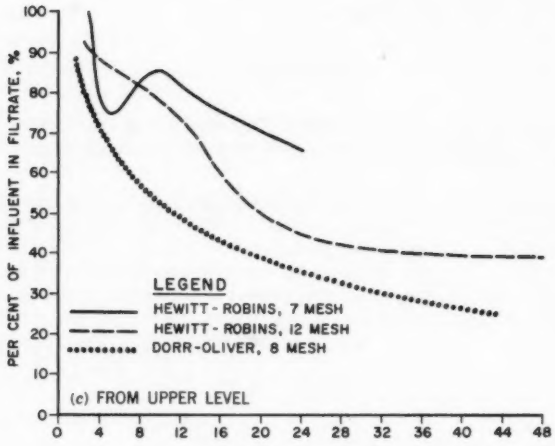


FIG. 8(c).—COMPOSITE CURVES OF FINE SCREENING PERFORMANCE FOR HYPERION DIGESTED SLUDGE FROM VARIOUS LEVELS

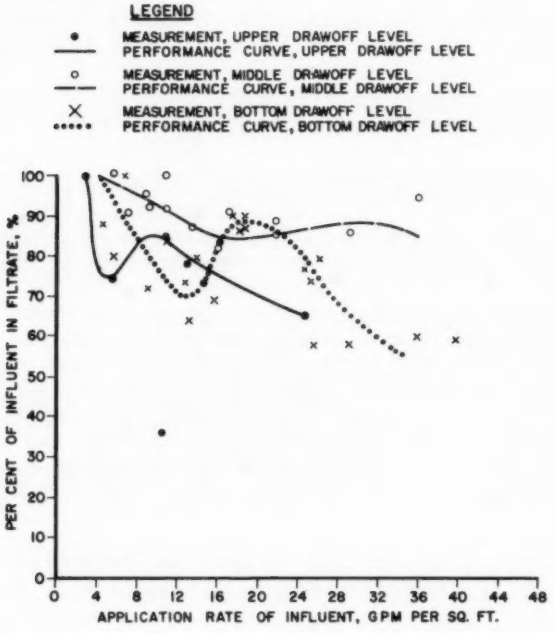

LEGEND
MEASUREMENT, UPPER DRAWOFF LEVEL
PERFORMANCE CURVE, UPPER DRAWOFF LEVEL
MEASUREMENT, MIDDLE DRAWOFF LEVEL
PERFORMANCE CURVE, MIDDLE DRAWOFF LEVEL
MEASUREMENT, BOTTOM DRAWOFF LEVEL
PERFORMANCE CURVE, BOTTOM DRAWOFF LEVEL
PER CENT OF INFLUENT IN FILTRATE, %
APPLICATION RATE OF INFLUENT, GPM PER SQ. FT.

FIG. 9.—COMPOSITE CURVES OF 7-MESH SCREEN PERFORMANCE FOR HYPERION DIGESTED SLUDGE FROM VARIOUS DRAWOFF LEVELS

In view of the pilot plant experiments and other considerations, fine screening is regarded as the most promising basic method for removal of floatables from the Hyperion digested sludge.

GRINDING

The possibility of grinding the entire digested sludge flow before discharge to the sea was considered. The objective of such grinding would be to reduce

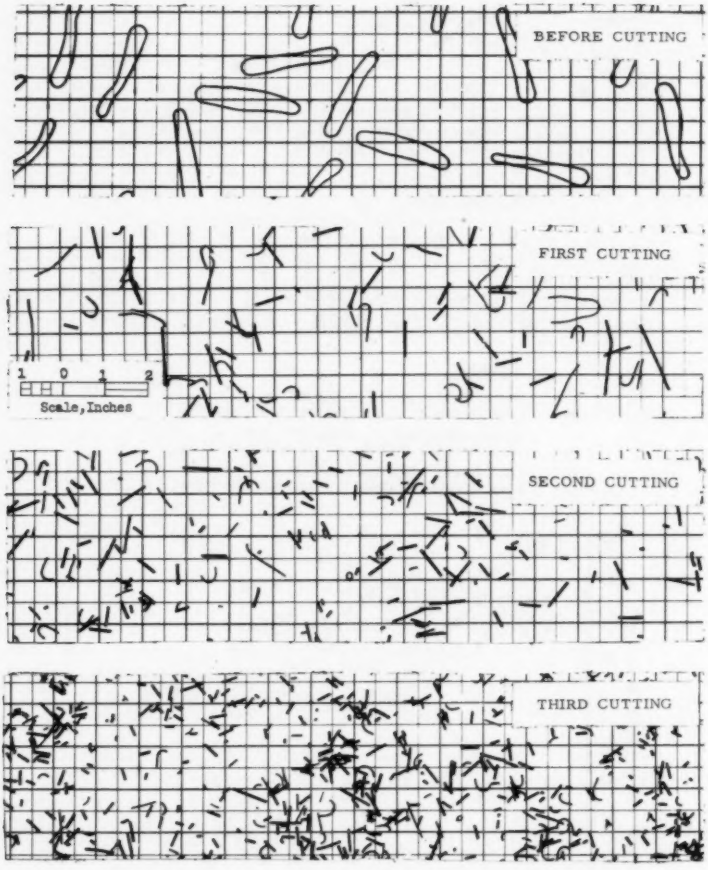


FIG. 10.—EFFECT OF MULTIPLE GRINDING UPON PARTICLE SIZE OF RUBBER BANDS

rubber particles to such a size that they would not constitute a problem. Various types of grinders were investigated in an attempt to find a machine that would grind all particles in a flow of 1700 gpm to a small size. The problem is complicated by the abrasive nature of the flow caused by its grit content.

The four disintegrators are in service at Hyperion for grinding screenings, and they have proven to be rugged and dependable. They use the shearing principle, with two lobes on the impeller shearing the solids as they pass through a series of sixteen slots in a grid plate. It also acts as a low-head pump, delivering about 250 gpm at 25 ft of head. Initial trials of rubber grinding with this machine indicated it would be necessary to obtain a finer grind. To affect this, a special grid plate was made containing a hundred and twenty 1/2 in. holes instead of the standard sixteen 3-1/8 in.-by-3/4 in. slots. Also the rotating element was changed to provide three lobes on the impeller. A large number of rubber bands were passed through this modified disintegrator. The first time through, most of the rubber bands were cut to about 3/4 in. to 1 in. They were then ground a second time, with further size reduction. After three passes, most of the pieces of rubber band were about 1/4 in. long. Fig. 10 shows the ground-up rubber bands after each grinding pass.

It was felt that reliance on grinding the digested sludge would be a dubious means of eliminating the floatables problem. However, grinding might be a valuable tool in accelerating digestion of rubber by reducing particle size, with the expectation that the smaller pieces would expose more surface area to the active agents of digestion.

One possible method of handling the reject material from a screening process would be to grind the reject and pump it to sea or back to the digesters for further decomposition. The screen reject would be comparatively free of grit because most of this would pass through the screens. Large samples of screening reject from the screening pilot plant were caught, mostly between 4% and 5% solids. This was passed through the modified grinder three times. Although there appeared to be some reduction in particle size by the grinding, there proved to be no practical way to sample and measure the ground material. However, the previously described experiments on rubber bands made it reasonable to assume that the grinding did in fact reduce the particle size.

DISPOSAL OF SCREENING REJECT

Assuming that all of the digested sludge were to be sent through No. 7 mesh stainless steel screen cloth before ocean disposal, the filtrate from the screens would be sent to sea without further processing. The remaining problem is how to handle the screen reject. The following possible means of processing the reject material were considered.

Land Fill.— There is no land available at the plant site for fill or burial of the screenings or sewage grit. The grit from Hyperion is trucked away and buried at another site several miles away. The present daily volume amounts to about 20 cu yd, roughly two truckloads per day. If it is assumed that screen reject would be 30% of the applied sludge, this reject from fine screening would be several hundred cubic yards per day. Even if screen reject could be reduced to 10% of the applied sludge, its mass would be difficult to handle and expensive to truck away from the Hyperion site. This method of disposal should be considered only if there is no other practical system.

Incineration.— The Hyperion Plant facilities include a sludge drier and incinerator, but incineration of sludge has not been practiced. The drying plant has been shut down since operation of the ocean outfall, since considerable expense is encountered in operating this equipment. More important, incinerators have become a vanishing novelty in smog-conscious Los Angeles County, and there is grave doubt that the existing sludge drying facility or

any other incinerator could be utilized for incineration of sludge screenings except possibly as a last resort.

Chemical Treatment.—It is conceivable that screenings or grindings could be digested chemically and then neutralized and disposed of in the ocean outfall for sludge discharge. However the required installation would be large and costly and the chemical expense would be prohibitive. The possibility of chemical weighting of the reject material for subsequent submarine discharge is unacceptable on grounds of cost, unreliability, and water pollution.

Air Drying.—Rubber deteriorates gradually under atmospheric exposure in the Los Angeles area primarily because of the unusually high ozone content of the atmosphere. It is conceivable that advantage might be taken of this action as a means of rubber decomposition by operating some kind of process affording an accelerated exposure. However no such process has come to the attention of the writers and the risk of nuisance and the probable costs discourage further consideration.

Multistage Grinding Preceding Ocean Discharge.—This scheme would incorporate sufficient disintegrator units to permit the entire screenings reject to be ground and reground without further processing until the effluenct could pass the number 7 mesh screen. With each grinding, the volume of coarse particles would be reduced. Following about 3 stages of grinding, the effluent would be directed onto a screen, the reject from which would be cycled back to further grinding. Rubber, cellophane, grease, and vegetable particles would be expected to be reduced in size fairly rapidly, while hairs would be reduced in size more gradually. Since the hair constitutes a substantial portion of screening reject, it might tend to soon accumulate to an unhandleable volume unless a large number of grinding stages was provided. This scheme would require a larger number of screening and disintegrator units for hydraulic reasons than would the other alternate schemes.

There is some doubt as to whether this grinding scheme would be entirely satisfactory because it has not actually reduced the rubber load in the ocean. It only reduces rubber particle size to where it may be unnoticeable.

Return of Grinding Effluent to Digestion System.—This general scheme gives the digestion process a further opportunity to reduce the floatables, taking advantage of the new particle surfaces exposed by the grinding process, and using longer digestion time. The effect of long-time digestion on rubber is not known. In an effort to obtain information on this, a pilot size digester is being charged with heavy rubber loads. No results are available (as of 1960) from this experiment. Since the normal digestion at Hyperion does deteriorate rubber to some extent, it appears reasonable to expect that with finer grinding of the rubber and much longer digestion, further deterioration of rubber will occur.

Special Digester Storage.—Under this scheme a number of individual digesters would receive the ground reject from the screens and would store this material as long as possible. The present digestion system consists of three batteries of digesters. In each battery there are four primary and two secondary digesters. At present there are ten primary digesters in regular use and two on a standby basis. The great bulk of gas evolution occurs in the active primary digesters. Most of the six secondary digesters are presently the repositories of vast accumulations of scum and are of little benefit in furthering the digestion process. These secondary digesters are undergoing a long range program of scum-breakup aimed at eventually making them available

for use as primary digesters, since secondary digestion is scheduled to be discontinued. Thus at the present time two of the twelve primary digesters are already available for possible storage and digestion of ground screenings reject.

Table 3 outlines the anticipated future schedule of the Hyperion digestion tank loadings based on operation as primary digesters.

Hyperion digested sludge drawn from the bottom of the primary digesters averages about 3.8% total solids and 0.4% dissolved solids. A 20 gpm per sq ft loading rate on a 7-mesh rectangular vibrating screen should yield about 85% filtrate and 15% reject by volume. It would be higher for upper drawoff level sludge. For design purposes a 30% reject is assumed. The screen reject has approximately 20% greater solids content than the influent. A typical reject for bottom sludge would be about 4.5% dry solids. Upper level sludge gives higher values and middle level sludge gives lower values than this, but neither is considered typical of normal operating conditions.

TABLE 3.—SCHEDULE OF LOADING OF HYPERION DIGESTERS WITH SCREENING REJECT IN SEGREGATED DIGESTERS

Year	Average Digested Sludge flow, in mgd	Active Primary Digester Retention, in Days	Active Primary Digester		Additional Digesters[a]	Secondary Digesters	Total Number of Digesters
			Total Capacity, in million gallons	Number in use			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1960	1.44	17.3	250	10	2	6	18
1980	1.94	16.7	325	13	5	0	18
2000	2.45	17.3	425	17	1	0	18

[a] Available for Screening Digestion.

For a present (1960) flow of 1.44 mgd of digested sludge at 3.8% of total dry solids, a flow of (0.30) (1.44) = 0.43 mgd would be rejected from the screens. This volume would be assumed to be returned in full to the digesters following grinding. The two digesters available would afford only (2) (2,500,000 gal)/0.43 mgd = 11.6 days retention under 1960 conditions. Under anticipated conditions in 1980, the five available digesters would afford a retention of (5) (2.5)/0.30 (1.94) = 21.5 days. However by the year 2000, there would be insignificant retention capacity available for ground screenings reject unless new structures were built.

The most discouraging aspect of this particular alternative is the low potential of the ground reject for further digestion when segregated from the main stream of digested sludge flow. The volatile solids of the digested sludge withdrawn from the digester are typically about 57% by weight. Experimental work by the plant personnel has shown that even when the digestion process is extended to 70 days, the volatile solids content is reduced only to about 53% by weight. The volatile solids in the raw sludge is about 78%. Based on an arbitrarily selected retention period of 70 days, the 17-day digested

sludge has experienced approximately

$$\frac{78 - 57}{78 - 53} = 84\% \text{ of its potential digestion.}$$

Although no experiments have been made on this aspect, there is no reason to believe that fine screening of the digested sludge results in any significant concentration of volatile solids in the reject. Hence the outlook for much additional reduction of rubber particles by long-time separate digestion, even in the presence of heat and moisture, is poor because of insufficient nutrient and culture.

Return to Active Digesters.—This scheme would return all ground screenings reject to the general influent of raw sludge to the digesters and would distribute this return material uniformly to all active digesters for further digestion. This is shown schematically in Fig. 11. Since the return material is already about 84% digested it would have only a minor effect on the volatile

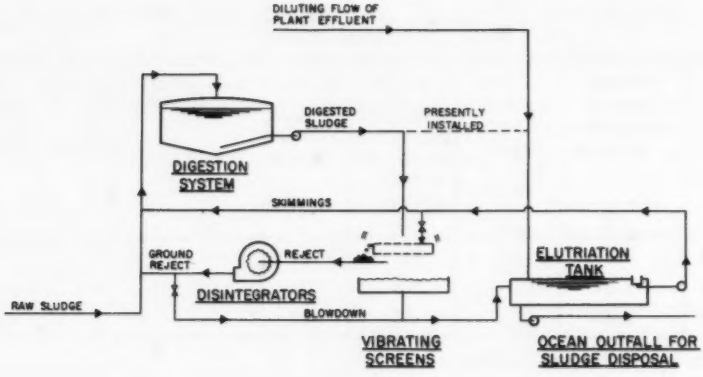


FIG. 11.—SCHEMATIC DIAGRAM OF PROPOSED FACILITY FOR REMOVING FLOATABLES FROM HYPERION DIGESTED SLUDGE PRIOR TO OCEAN DISCHARGE

solids loading of the digesters. The main effect would be a volumetric swelling of the normal raw sludge input resulting in a digester retention time which would be a function of how great a bulk of recycling material is permitted.

CONSIDERATIONS OF CYCLING LOAD

General.—When a constant stream of digested sludge or any other suspension is intercepted by screens which allow less than 100% of the flow to pass, then if the rejected portion is returned eventually to the main stream the hydraulic loading on the screens will be increased proportionately. This new hydraulic loading may of itself have an effect of increasing the percentage of flow rejected by the screens. If this were true and the process is continued in this manner, the recycling flow will grow indefinitely in volume, posing a

serious problem. This tendency becomes even more real if there is no provision for reduction of the size of rejected particles in suspension to a value which permits their ready passage through the screens on their second pass of screening. It is apparent that while the intermediate processes of grinding and redigestion will reduce particle size, there will still be a necessity of removal of surplus cycling flow by "blowdown" in order to maintain control of the whole process.

There is no precise way of predicting how large the cycling flow of screenings will become. However, for the proposed design, it is assumed that for a gross ultimate hydraulic screen loading of 20 gpm per sq ft the recycling flow will not have exceeded 60% of basic sludge flow. This assumption is considered conservative especially since experiments at Hyperion and also recent experiments at Los Angeles County Sanitation Districts' Joint Disposal Plant, have shown that when digested sludge is applied to vibrating screens at a low or moderate hydraulic loading rate a fairly high degree of dewatering is attainable. This type of operation will be possible during much of the time with the proposed facility, and will help control the cycling load.

TABLE 4.—DIGESTER LOADING SCHEDULE FOR GENERAL RECYCLING OF GROUND SCREENINGS REJECT TO DIGESTION SYSTEM

Year	Average Digested Sludge flow, in mgd	Recycled Ground Screenings Reject at 60% max	Total flow[a] in mgd	Primary Digestion Capacity			Number Secondary Digesters	Total Number of Digesters
				Retention Days, min	Available Digesters			
					in million gal	number of		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1960	1.44	0.86	2.30	13.1	30	12	6	18
1980	1.94	1.16	3.10	14.5	45	18	0	18
2000	2.45	1.47	3.92	11.5	45	18	0	18

[a] Digested Sludge plus reject.

Digester Retention.—Under the assumption outlined, the schedule of digester loadings would therefore become as shown in Table 4.

The digester retentions for the first 20 yr would be from about 13% to 25% less than those presently (1960) experienced. If found necessary, additional digestion capacity could be added. The ground screenings reject would cycle continuously through the sludge treatment portion of the plant under this scheme and would be held to a maximum of 60% of basic sludge flow by controlled blowdown. The eastern elutriation tank would receive the filtrate of the vibrating screens and would continue to receive the diluting flow of plant effluent used to keep the sludge ocean outfall flowing at desired hydraulic condition. Skimmers and scum collectors would be provided for removal of floating material prior to ocean discharge. The float would be pumped back into the digesters for further digestion. At opportune times it might be pumped directly to the screens for dewatering and solids removal.

The total volume of skimmings would, normally, not exceed 10% of the elutriation tank flow or about 14% of the main stream of digested sludge and recycling ground screening reject. The skimming facilities would be so arranged that most of the rubber material would be removed in the first two of four existing launders for return to the digestion system. The remaining skimmings flow would be returned to the general plant flow.

Flotation in the elutriation tank would be expected to catch at least 70% of any rubber particles and to return them to the digesters with other floating material. Much extraneous material, suitable for ocean discharge, would be settled out and pumped to sea. Recycled rubber particles would probably undergo some degree of decomposition with each additional pass through the digesters and some reduction of size with each pass through the disintegrator. These two actions would combine to prevent an uncontrolled buildup of rubber particles in the digestion system since small particles capable of passing a number 7-mesh screen would be bled off with each pass.

Blowdown.—The automatic blowdown feature would be controlled hydraulically and would bypass surplus screening reject to the elutriation tank whenever a surplus should occur. The bypass would be designed to permit additional dewatering of the surplus reject if necessary. Facilities would be provided for physical removal of this surplus reject. Since rubber is not distributed homogeneously throughout the digesters but is generally confined to the scum layer, it would normally be possible to schedule periods of rubber withdrawal from the digesters when the blowdown rate is at a minimum, thus largely excluding rubber from the elutriation tank. With these various barriers, the number of native-state rubber particles which would be discernable by eye in the ocean discharge would be insignificant.

Of all the constituents within the screening reject, hair is anticipated to be the most difficult of disposal. Hair is relatively inert to digestion and consequently its primary means of reduction must be by grinding. It is anticipated that this will be effected satisfactorily by the disintegrators. Surplus recycling hair in the blowdown can properly be discharged into the elutriation tank and thence disposed of directly into the ocean outfall for sludge disposal, since hair in the submarine discharge remains well submerged and has presented no problem in the receiving waters.

Possibilities of Dewatering for Fill.—Disposal of screening reject by land fill has indicated to be impractical as a primary means of disposal. Even if dewatering to a relatively high degree by vibrating screens were found possible, there would still be certain necessary structures to build and physical handling to perform in order to dispose of floatable solids by removal from the system. The handling of such solids in a liquid phase is normally much simpler and convenient than handling them in a solid phase. Present considerations (1960) do not favor solid phase removal except for limited and selective removal of screened blowdown. Facilities are proposed to permit this operation. Design of the facilities would also permit adaptation to a solids removal operation if future experience demonstrates that this is both practical and economical.

PROPOSED SLUDGE TREATMENT FACILITIES

Method.—Return of ground screenings reject to the plant digestion system is the most feasible and logical method of removing floatables from the Hy-

perion sludge outfall discharge and is therefore recommended. Multistage grinding of screening reject is possible at average flows.

TABLE 5.—DESIGN CRITERIA FOR FLOATABLES REMOVAL IN HYPERION DIGESTED SLUDGE PRIOR TO OCEAN DISCHARGE

Item	1960	1980	2000
Average Sludge Flow, gpm	1000	1350	1700
Average Sludge Flow, mgd	1.44	1.94	2.45
Peak Sludge Flow, gpm	1500	2020	2550
Peak Sludge Flow, mgd	2.16	2.91	3.68
Screening Reject Flow at 60%			
Average Rate, gpm	600	810	1020
Average Rate, mgd	0.80	1.16	1.47
Peak Rate, gpm	900	1215	1530
Peak Rate, mgd	1.30	1.75	2.20
Screening, Rate, gpm per sq ft			
Average Flow Condition	10.0	13.5	13.6
Peak Flow Condition	15.0	20.2	20.4
Total Active Screen Area, sq ft	160	160	200
Number of Active Screen Units	4	4	5
Number of Standby Screen Units	1	1	1
Number of disintegrators at 250 gpm			
Active use at average flow	4	4	5
Standby at average flow	1	1	1
Active use at peak flow	5	5	6
Standby at peak flow	0	0	0
Number of Return Pumps at 600 gpm			
Active use at average flow	1	1 to 2	2
Standby at Average flow	1	1	1
Active use at peak flow	1 to 2	2	3
Standby at peak flow	0	0	0
Elutriation Tank Dilution			
Dilution Ratio, Water: Sludge	2.30	1.45	1.91
Elutriation Tank Flow, mgd			
Sludge Fraction	1.44	1.94	2.45
Diluting Water	3.31	2.81	4.69
Total Flow	4.75	4.75	7.14
Underflow to Ocean Outfall	4.32	4.32	6.49
Skimmings Flow, Total	0.43	0.43	0.65
Skimmings to Sludge Treatment	0.22	0.22	0.33
Skimmings to Plant Flow	0.21	0.21	0.32
Elutriation Skimmings Pumps			
Number Required at 400 gpm	1	1	2
Average Per cent of Time in Use	38.2	38.2	28.6

Design Criteria.—The basic design criteria are indicated in Table 5.

Description of Facilities.—The required facilities include (1) sludge treatment building, (2) elutriation tank modifications, (3) skimmings pumping fa-

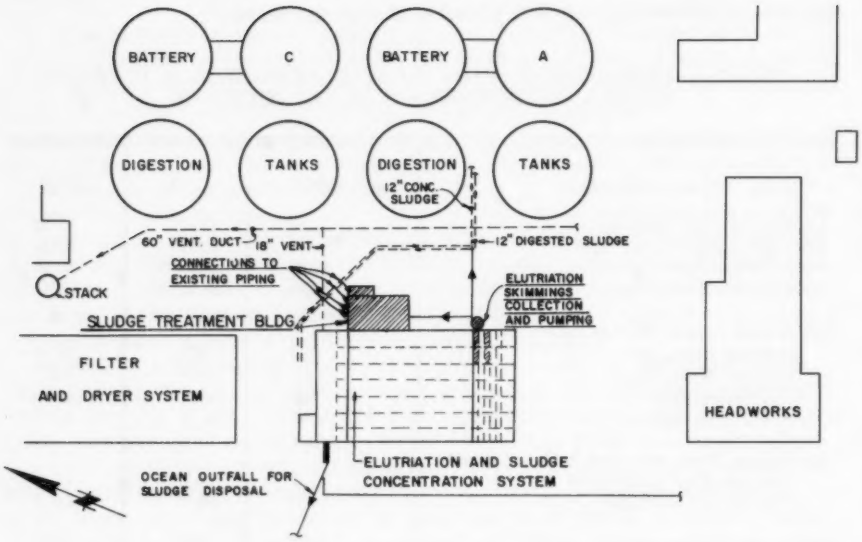
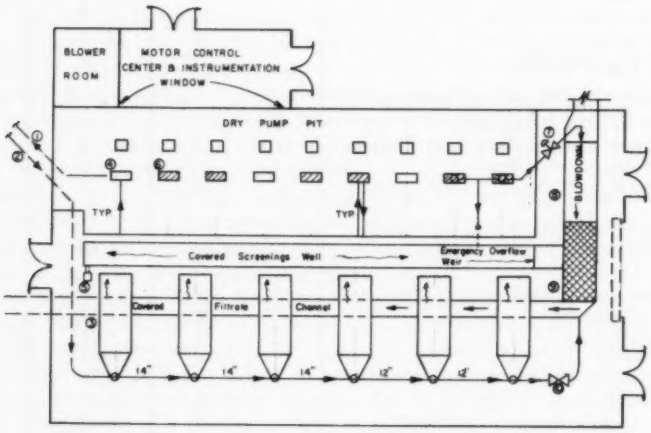


FIG. 12.—PROPOSED SLUDGE TREATMENT FACILITIES AT HYPERION



LEGEND

① GROUND SCREENINGS RETURN
② DIGESTED SLUDGE INFLUENT
③ 4'X 10' VIBRATING SCREEN, TYP.
④ 500 GPM RETURN PUMP, TYP.
⑤ CONTROL FLOAT WELL
⑥ DISINTEGRATOR, TO & FROM SCREENINGS WELL, TYP.
⑦ AUTOMATIC, FLOAT-CONTROLLED, BLOWDOWN VALVE
⑧ AUTOMATIC BLOWDOWN SCREEN
⑨ REMOVABLE DRAINBOARD FOR BLOWDOWN SCREENINGS
⑩ DIGESTED SLUDGE BY-PASS VALVE, NORMALLY CLOSED

FIG. 13.—PLAN OF HYPERION SLUDGE TREATMENT BUILDING

cilities, and (4) yard piping, ventilation connection, and general site work. The proposed location of the facilities is as shown in Fig. 12.

The sludge treatment building will be a single-story, reinforced concrete structure housing the vibrating screens, disintegrators, return pumps, monorail hoist, piping, controls, electrical gear, instrumentation, and miscellaneous equipment and appurtenances for the basic sludge screening, grinding, and solids removal facilities. A conceptual floor plan is shown in Fig. 13. The electric motors and wiring within the main room would be explosion-proof. Instrumentation, telephone, and switchgear would be located in a separate room with outside access and positive ventilation and with a fixed window affording a view of the main room.

Flow to individual screens would normally be split equally by automatic, diaphragm-type, modulating valves and will be metered by sludge metering Venturi tubes with pneumatic converters and flow indicators. Individual screen flow meterings will be combined and indicated automatically. Malfunction alarms will be transmitted to digester battery "A" control room.

Operation of the facilities will be automatic and no resident operator will be required. The starting and stopping of vibrating screens will be a manual operation but they will normally be left running. At least one screen (the blowdown screen) and possibly an additional screen will be automatically controlled by liquid level in the screenings well. This well will catch the screenings reject and recirculated discharge from the disintegrators and will serve as the forebay for the disintegrators and return pumps. Layout will facilitate conversion to dewatering and solids removal if this is found to be desirable in future operations.

Ventilation will be by blower into the existing exhaust duct into the stack. High pressure effluent will be used as required for screenings well makeup water and for screens spray jets.

As indicated in Table 5, standby screens and disintegrators will be provided permitting at least one machine to be out of operation for maintenance or repairs. Disintegrators will normally run continuously thereby accomplishing the most grinding possible. Return pumps will not need to have a standby unit for peak flows because of the emergency gravity connection to the elutriation tank.

Elutriation tank modifications will consist of installation of additional water surface sprays, utilizing high pressure plant effluent and modification of two of the existing launders to accomplish scum removal. The latter work will involve installation of two or more scum beaches and gravity or mechanical scum collection devices conveying skimmings into a manhole to be constructed immediately adjacent to the eastern elutriation tank. Necessary bypasses will be provided.

Skimmings pumping facilities will be located within the new skimmings manhole and will consist of a vertical submersible solids type pump and electric motor together with electric supply cable and discharge piping connection. Space and piping will be provided for two pumps, but only one pump will be provided initially. A standby pump is not considered essential in the first years since surplus skimmings, as they may occur, may be returned automatically to the plant influent. Eventually a second pump will be added. Control will be automatic through the use of a float.

Yard piping, ventilation connection, and general site work consist of the following projects. Digested sludge will be intercepted from the existing 12-

TABLE 6.—COST ESTIMATE

Description (1)	Estimated Quantity (2)	Unit (3)	Unit Cost (4)	Total Cost (5)
SLUDGE TREATMENT BUILDING				
Basic Structure 40 ft by 80 ft, Split Level, 15 ft high max	3,200	sq ft	$ 16.00	$ 51,200
Mono-Rail and 3-Ton Hoist	1	Each	9,000.00	9,000
Ventilation Facility	1	Job	L.S.	6,000
Vibrating Screens, Complete	6	Each	4,200.00	25,200
Return Pumps, Complete	2	Each	4,800.00	9,600
Disintegrators, Complete	5	Each	9,000.00	45,000
Interior Piping	1	Job	L.S.	10,000
Electrical Work, Complete	1	Job	L.S.	20,000
Instrumentation and Controls	1	Job	L.S.	25,000
Site Preparation, Local	1	Job	L.S.	2,000
Miscellaneous	1	Job	L.S.	10,000
		Subtotal, Sludge Treatment Building		$213,000
EXISTING ELUTRIATION TANK				
Furnish and Install Scum Collection Facilities in Exist. Effluent Channels(2)	1	Job	L.S.	$ 22,000
Furnish and Install Surface Sprays for Scum Collection	1	Job	L.S.	2,000
		Subtotal, Existing Elutriation Tank		# 24,000
ELUTRIATION SKIMMINGS PUMPING				
Construct Special Manhole for Elutriation Skimmings	1	Job	$ L.S.	$ 2,500
Furnish and Install Piping	1	Job	L.S.	1,500
Furnish and Install Submersible Sludge Pump and Motor Unit	1	Each	3,000.00	3,000
Electrical Work Including Control	1	Job	L.S.	3,000
		Subtotal, Elutriation Skimmings Pumping		$ 10,000
YARD PIPING, VENTILATION CONNECTION, AND GENERAL SITE WORK				
Construct 12 in. CIP Lines	130	linear ft	$ 15.00	$ 1,950
Construct 12 in. VCP Duct	45	linear ft	10.00	450
Construct 6 in. CIP Lines	200	linear ft	8.00	1,600
Miscellaneous Valves, Fittings, and Connections	1	Job	L.S.	4,000
Concrete Paving	5,000	sq ft	0.80	4,000
Remove Existing Shrubs	1	Job	L.S.	500
Landscaping	1	Job	L.S.	1,500
		Subtotal, Yard Piping, Vent., Con. and Gen. Site Work		$ 14,000
		Totals		$261,000
		15% for Contingencies and Unforseen Costs		$ 39,200
		TOTAL ESTIMATED CONSTRUCTION COST		$300,200

in. line from the digesters to the elutriation tanks. Filtrate will be returned to this line. Ground screenings will be pumped back to the digestion system influent via an existing, unused 12-in. concentrated sludge line. A piping connection to this line will be made for return of elutriation tank skimmings.

The exhaust air from the sludge treatment building will be directed into the existing 60-in. ventilation duct to the stack.

Site work will include necessary grading, paving, and landscaping. Truck access to the monorail hoist and to the point of possible solids removal will be provided. Flexibility permitting various types of solids handling equipment will be incorporated.

Table 6 indicates the cost estimate for these alterations.

SUMMARY

1. Los Angeles' Hyperion Treatment Plant has abandoned the production of fertilizer and has provided a 7-mile long ocean outfall for disposal of digested sludge into deep water.

2. At the time of sludge outfall design, it was anticipated that minor portions of the digested sludge might float to the ocean surface. It was decided to postpone the design and construction of facilities to cope with the "floatables" problem until full-scale operation of the sludge outfall defined the nature and extent of the floatable material.

3. Actual operation of the sludge outfall has resulted in occasional appearance of small particles of rubber and some cellophane in the ocean and on the beach. These incidences are on the increase.

4. Preliminary laboratory experiments indicated that elutriation and dilution of digested sludge with either plant effluent or sea water would cause the sludge particles either to rise to the surface or settle out.

5. An hydraulic classification pilot plant was constructed which provided for dilution of digested sludge with plant effluent; rapid and slow mixing; settling; and surface, bottom, and intermediate drawoff of the processed sludge.

6. The hydraulic classification experiment showed that most of the time it would remove over 70% of the rubber particles. Because this was not regarded as sufficiently successful to prevent floatables in the ocean the experiment was abandoned.

7. A screening pilot plant was set up to pass digested sludge through a vibrating horizontal screen or a concave stationary screen.

8. Both types of screens removed all identifiable rubber particles from the digested sludge.

9. Various types of screen cloth were tested. The most effective screening was accomplished by using a stainless steel screen cloth with 7 wires per inch with 0.096 opening, mounted on the vibrating screen.

10. The screening tests showed that a practical application rate for digested sludge would be 20 gpm per sq ft of screen. At such a rate about 80% of the applied sludge would pass through the screen as filtrate, and the remaining 20% was rejected by the screen.

11. A disintegrator was modified to cause it to grind particles to a smaller size than normal. New rubber bands and material rejected by the 7-mesh vibrating screen were passed through the modified disintegrator. This grinding operation reduced the size of particulate matter by a noticeable but unmeasured amount.

12. The possibilities of disposing of screening reject material by incineration, chemical treatment, air drying, or multi-stage grinding with pumping to sea were considered and rejected as being uneconomical or undependable.

13. Disposing of screening reject material, by trucking away and burial is conceivable under the most favorable circumstances, but at best would be cumbersome and expensive. Disposal by burial is therefore not planned for as a primary treatment method.

14. There is adequate digestion capacity at Hyperion to allow return of ground screening reject to the digesters for further decomposition.

15. The most feasible scheme for removing floatables from 2.45 mgd of digested Hyperion sludge prior to ocean disposal would incorporate the following:

(a) Interception of all sludge flow from the digesters by six parallel 4 ft-by-10 ft vibrating screens equipped with 7-mesh stainless steel cloth.

(b) Piping from filtrate side of screens to the ocean outfall for sludge disposal via the east elutriation tank.

(c) Six modified disintegrators for grinding screen reject.

(d) Pumps and piping to allow return of ground reject material to the digestion system.

(e) A suitable building to house the screens, grinders, and related equipment.

(f) Automatic blowdown facilities for relief of potential surplus ground screening reject to the east elutriation tank.

(g) Combined elutriation - dilution of screenings filtrate and screenings blowdown with hydraulic classification of floatable material and removal of such material by skimming.

(h) Return of elutriation tank skimmings by pump to the plant digestion system or to the vibrating screens for subsequent treatment.

(i) Provision for dewatering of surplus solids by vibrating screens and physical removal from the system.

(j) Adaptability of the liquid phase treatment process to a solids phase removal process for possible future use.

16. The estimated construction cost of the necessary sludge treatment facilities is approximately $300,000.

Journal of the
SANITARY ENGINEERING DIVISION
Proceedings of the American Society of Civil Engineers

DISCUSSION

Note.—This paper is a part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 87, No. SA 2, March, 1961.

DIFFUSERS FOR DISPOSAL OF SEWAGE IN SEA WATER[a]

Closure by A M Rawn, F. R. Bowerman, and Norman H. Brooks

A. M. RAWN,[25] HON. M. ASCE, F. R. BOWERMAN,[26] M. ASCE and NORMAN H. BROOKS,[27] M. ASCE.—Mr. Jordaan has suggested the possibility of directing the sewage jets downward, instead of horizontally, to increase the efficiency of mixing with bottom waters. But as also pointed out by the discusser, elaborate precaution must be taken to protect the ocean bottom from scour that might undermine the pipe itself. It is doubtful whether the additional benefits would warrant the additional costs. If greater dilution is necessary, the cheapest method for achieving it is most likely to be the provision of a greater number of ports of smaller diameter.

Futhermore, the amount of dilution is limited by the amount of clean diluting water drawn into the mixing area. Intense but localized turbulence may not effectively increase dilution but only produce a more homogeneous sewage field. An essential feature of a diffuser is the wide dispersal of the effluent to limit mutual interference between rising columns (or plumes) and make vast quantities of uncontaminated dilution water readily available for entrainment.

Many different outlet devices were considered and tested during the investigation, including nozzles, long and short slots, circular manifold chambers, aspirators and jet pumps, swirl devices, baffles, and the like. Unit for unit many devices could be shown to provide more rapid mixing than a simple port, but to achieve any specified result the provision of a sufficient number of ordinary ports is cheaper, simpler, and easier to maintain over long periods in a submerged condition than a smaller number of more complicated devices.

Mr. Lawrence has clearly and correctly emphasized that when diffusers are used the rate of further natural dilution in the sewage field is decreased. This problem has not been analyzed in this paper, but a comprehensive analysis of the sewage field has been presented elsewhere.[28] However, with multiport diffusers, there is a net increase in dilution at the shore, but proportionately less than at the outfall termini. Basically, a larger share of the ultimate

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[a] March 1960, by A M Rawn, F.R. Bowerman, and Norman H. Brooks (Proc. Paper 2424).

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[28] "Diffusion of Sewage Effluent in an Ocean Current," by N. H. Brooks, Proceedings, First International Conference on Waste Disposal in the Marine Environment, Univ. of California, Berkeley, Calif., July, 1959.

mixing has been put under man's control, providing definite protection against contamination that might result from unusually rapid shoreward drift of poorly diluted sewage.

Benefits, therefore, should not be evaluated simply by averages without regard to dispersion of values. The magnitudes of the counts that are in violation of the standard of 10 coliform organisms per ml should be considered. For example, a violation of 1,000 organisms per ml is more serious than one of 50 organisms per ml. For the discharge from the diffusers operated by the Los Angeles County Sanitation Districts, the highest coliform counts are less than 1/10 of what the extreme values would otherwise have been. (It is difficult to analyze high counts quantitatively because many are indicated only by all positive tubes in the dilution tube technique when tube dilutions are set up in expectation of getting resolution for smaller coliform counts).

Since the earlier analysis of data, terminating with calendar year 1958, additional information concerning the operation of diffusers has been tabulated for calendar years 1959 and 1960. Table 5 shows the average sewage flow thru the outfall system for the years 1957 through 1960, and shoreline bacterial

TABLE 5.—COLIFORMS AT SHORE STATIONS SUBSEQUENT TO INSTALLATION OF DIFFUSERS

Year	Annual Percentage of Coliform Counts Exceeding 10 per Milliliter at Shore Stations (See Fig. 3)					Average Annual Effluent Discharge, in Million Gallons Daily
	Station					
	1	2	3	4	5	
1957	2	4	26	22	6	195
1958	11	9	15	5	13	218
1959	2	7	11	6	6	248
1960[a]	4	12	8	10	5	266

[a] Intermittent Chlorination Commenced During 1960.

data for the 4-yr period during which the two larger diffusers have both been operating. It should be noted that the average sewage flow has increased from 195,000,000 gal daily in 1957 to an average of 266,000,000 gal daily during 1960, an increase of 37%. During the 3-yr period 1957-1959, the annual percentage of coliform counts exceeding 10 per ml at Station 3, the closest to the outfalls, decreased from 26% to 11%. (For locations of shore stations see Fig. 3). The data for 1960 are not directly comparable with earlier data, for commencing in 1960, the Sanitation Districts have operated a disinfection system using direct liquid chlorination during those short periods of the year when conditions in the receiving waters are such as to inadequately protect the shoreline from receiving sewage effluent-sea water mixtures in concentrations that exceed the requirements of the Regional Water Pollution Control Board. Periods requiring chlorination of the primary effluent have been determined to coincide with the following co-existing unfavorable conditions:

1. Onshore winds having velocities exceeding about 10 knots and persisting for twelve or more hours; and

2. A temperature spread between the ocean water at the surface and at the bottom of the ocean in the vicinity of the diffusers of less than 6 F.; that is, essentially an isothermal ocean, without the thermocline necessary to the submergence of the sewage field.

Chlorination is utilized only in those instances in which oceanographic and meteorologic conditions limit the capability of the diffusers to disperse the sewage effluent within safe limits. During 1960, chlorination was deemed desirable for a total of 70 days, some 19% of the time; conversely, 81% of the time the outfall system satisfactorily disposed of an average of 266,000,000 gal daily of primary effluent without benefit of chlorination and without detriment to the ocean shoreline.

LIGHT CONVERSION EFFICIENCY OF ALGAE GROWN IN SEWAGE[a]

Discussion by Harold B. Gotaas

HAROLD B. GOTAAS,[22] F. ASCE.—The author has presented significant new information concerning the influence of some of the different variables in "engineered photosynthesis" on the efficiency of the conversion of light energy to plant life in the "stabilization pond" process for sewage treatment. This study is another important step in the development not only of more effective and economical waste treatment, but also of a method for reclaiming valuable and necessary nutrients and water now being wasted after considerable expense to make the waste reasonably safe to throw away. The so-called "stabilization pond" process as presently utilized involves a range of operating conditions varying from extensive dilution of waste waters in large ponds or lakes with BOD loadings of 10 lb to 20 lb per acre per day in which oxygen for biological oxidation is supplied mainly by atmospheric reaeration to a system in which biological oxidation of organic matter is accompanied by photosynthetic growth of green algae that releases oxygen to meet most of the biochemical oxygen demand permitting loadings of over 100 lb of BOD per acre per day. Light, being the source of energy, is an essential and limiting factor in photosynthetic oxygenation for high loadings of stabilization ponds. The results of the fundamental laboratory experiments by the author point out the influence of several of the different dependent and independent variables in the system, namely certain species of unicellular algae, detention period in the growth unit, available carbon-dioxide, light intensity, daily light duration, BOD of the waste, temperature, and pH on the efficiency of light conversion for these specific conditions. These laboratory data are basic to better understanding the design and operation of large outdoor ponds but permit only limited direct transfer or extrapolation to the varying conditions in an outdoor pond. The author's optimization of the variables as a measure of maximum productivity and the finding of maximum productivity at between 12.5 and 17.5 calories per liter of waste per min are significant. These values no doubt are applicable to outdoor ponds, but it will be necessary to find a measure of usable light received in the pond. Because the light on the pond surface is of high intensity and decreases rapidly with depth, it is now difficult to determine just how many calories of proper intensity light are received by the algae in an outdoor pond.

The stabilization pond has such an important potential for economical and effective waste treatment and reclamation that extensive efforts should

[a] July 1960, by W. J. Oswald (Proc. Paper 2558).

[22] Dean and Prof. of Civ. Engrg., Northwestern Univ., Tech. Inst., Evanston, Ill.

be made to obtain more basic laboratory information coordinated with field information so that further optimum design and operating criteria can be developed. However, unless harvesting or removal of the algae can be accomplished, it is doubtful that the high rate ponds that make maximum use of light energy to produce greatest photosypthetic oxygenation will be as economical as larger ponds that convert less of the nutrients to algae.

The use of other types of algae, their relationship to light conversion and growth efficiency, harvesting and reclaiming the algae, mixing and recirculation are important factors in the further development of the stabilization pond process. For example, it has been thought that small unicellular algae that are relatively free floating are most effective for photosynthetic oxygenation. However, recent studies[23] show that Oscillatoria, a filamentous alga, grows well and produces approximately as high yields in organic wastes as do Chlorella or Scenedesmus.

Because algae grown in sewage contain the essential nutritive elements for life and are particularly high in protein (35 to 60%), and because the algae can undergo some decomposition in a receiving stream, harvesting of the algae grown in stabilization ponds operated to produce high algae concentrations is an important factor in future developments of the stabilization pond process. The unicellular algae are very difficult to remove from the liquid effluent of the pond. So far economical harvesting methods for unicellular algae have not been developed.

Present stabilization ponds that are operated to make use of photosynthetic oxygenation contain small unicellular algae that, to a considerable degree, remain suspended and float to the pond effluent. Considerable coagulation and sedimentation of the decomposing organic matter takes place in the pond. The settled material continues to decompose aerobically if oxygen is available or otherwise anaerobically and some of the decomposition products become available as food for the algae. Hence, three phases of biological growth exist in the pond; (1) stabilization of a large amount of the organic matter on the pond bottom, (2) stabilization of organic matter by bacteria suspended in the liquid, and (3) algae growth on the top part of the liquid where the light can penetrate. Unless mixing is used, the top part of the pond contains the floating algae and most of the oxygen but too little nutrients to sustain a high yield of algae moving through the pond. If some type of filamentous algae could be developed to grow as stationary, branching threadlike networks around and through which the liquid can flow, more efficient pond operating conditions from the standpoint of oxygen supply, yield of algae, detention time and harvesting might be achieved. Even though the specific growth rate of the filamentous algae cells were less than that of the unicellular algae, the larger concentration of filamentous algae remaining in the pond might make possible a larger yield per unit area of pond surface. A problem of practical significance is whether or not small unicellular algae would overgrow and shade out the filamentous algae suspended more or less vertically or partially rooted on the bottom. It appears that if the detention time of the liquid in the pond could be made sufficiently short, the small freefloating algae would be washed out of the pond and could not build up sufficient concentration to prevent the growth of stationary filamentous algae. The filamentous algae could be harvested by a dipping or forking operation, filtered to a cake and dried

[23] Culture of Oscillatoria in Organic Wastes, Gaur, Pipes, and Gotaas, Journal of the Water Pollution Control Federation, 32, p. 1060, October 1960.

economically. The author pointed out the inhibiting of bacterial decomposition by the high pH produced by the algae as well as the fact that high bacteria densities near the pond surface absorbed considerable of the light thus reducing the light available to the algae, It appears that partially rooted filamentous algae grown vertically in the pond without mixing might better utilize the nutrients released from the pond bottom and make greater use of the total light available to the pond.

The facts that the population is increasing at the rate of doubling once approximately every 40 yr and that in the near future about 70% to 75% of the population will be in urban centers, emphasize the importance of engineered photosynthesis for waste treatment and disposal. Most of the organic materials brought to cities eventually enter the sewerage system or are discharged to the atmosphere. The portion of waste that can be disposed to either water courses or the atmosphere is becoming lower and the need to remove or reclaim more of the material is becoming greater. In some areas of the world the return of urban wastes to the agricultural land has been essential to survival. Investigations of stabilization ponds show that the photosynthetic efficiency in converting waste nutrients into plant life and yield per unit area of land are higher for algae grown in stabilization ponds than for land plants. Also the percentage removal of the nutrients from waste waters can be high thus yielding an effluent water that can be easily reclaimed. Water loss by evaporation from the pond surface is less per unit weight of material harvested than transpiration losses for land crops. It is possible that the further development of stabilization ponds will permit the conversion of an obnoxious material that now costs large sums to treat for satisfactory disposal, to a high protein plant food for animals, and to plants from which certain materials and energy can be extracted.

The paper by Mr. Oswald has ably furnished new data essential to more effective development of "engineered photosynthesis" to meet environmental control, reclamation and production problems for the future.

THE SOLUBILITY OF ATMOSPHERIC OXYGEN IN WATER[a]

Discussion by I. C. Hart and A. L. Downing

I. C. HART,[14] and A. L. DOWNING.[15]—The excellent work carried out by the Stream Pollution Control Section of the Tennessee Valley Authority and Morris and his colleagues at Harvard University has revived controversy regarding the saturation values for oxygen in water. It is difficult to account for the differences between the values reported by these groups on the one hand that are also in agreement with much earlier values due to L. W. Winkler,[16] and the values obtained in the writer's Laboratory by Truesdale, Downing, and G. F. Lowden that are supported quite well by the determinations of J. P. Jacobsen[17] and of A. Krogh and E. Lange[18] and rather less well by those of K. Berg.[19] These differences are the more perturbing because all these workers determined the concentration of dissolved oxygen by the Winkler procedure or by modifications of this method that differed only in the way in which the iodine formed in the Winkler reaction was estimated. In an attempt to clarify the present rather unsatisfactory position, further measurements are being made in the writer's laboratory. These have consisted, so far, of a comparison of the results given by some of the procedures used by the different groups and of a redetermination of the saturation values at 10 C and 25 C, using the analytical procedure adopted by the TVA group.

Comparison of Analytical Procedures.—Initially, attention has been concentrated on comparing the TVA method with that used by Truesdale, Downing, and Lowden (TDL method) and that of the conventional Winkler method described in the American Public Health Association's Standard Methods.[20] The only deliberate departure from the published procedures was that A. R. potassium iodate was used as a primary standard because potassium bi-iodate (used by the TVA group) of adequate purity was not commercially available in Britian. However, the work of Morris indicates that iodate and bi-iodate are interchangeable.

The main findings that have emerged so far are that for water, approximately in equilibrium with atmospheric air, the TVA procedure, gave results

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[a] July 1960, by 29th Report, Committee on Sanitary Engrg. (Proc. Paper 2556).

[14] Water Pollution Research Lab., Elder Way, Stevenage, England.

[15] Water Pollution Research Lab., Elder Way, Stevenage, England.

[16] Ber dtsch Chem. Ges., by L. W. Winkler, 1889, 22, 1764.

[17] Medd. Kom. Havunders, Ser Hydrogr., by J. P. Jacobsen, 1905, 1, No. 8.

[18] Int. Rev. Hydrobiol., by A. Krogh and E. Lange, 1932, 26, 20.

[19] Fol. Limnol. Scand., by K. Berg. 1943, No. 1, 174.

[20] "Standard Methods for the Examination of Water, Sewage and Industrial Wastes," Amer. Pub. Health Assn., 10th Ed, 1955, New York, p. 252.

on the average 0.22 ppm higher than the TDL method for water at 10 C and 0.13 ppm higher at 25 C, whereas the results obtained by the latter method and by the conventional Winkler method were the same to within about 0.02 ppm. The results obtained by a variation of the conventional Winkler method in which the iodine was measured out by pipette instead of by measuring cylinder, were not significantly different from the unmodified procedure. Differences identical with those mentioned were also obtained when the iodine formed by the Winkler procedure in the TDL method was pipetted directly into excess thiosulphate as in the TVA method, instead of into the empty titration vessel to which 0.4% excess solid A.R. potassium iodide was added, as in the TDL method.[21]

Loss of iodine by volatilization in the TDL procedure seemed to be one possible reason for the previous differences. To provide further information about this phenomenon, 10-ml aliquots of a solution of iodine, formed by the Winkler reaction, were stirred for varying periods in an open beaker similar to that used for the TDL procedure and the residual iodine was then determined. When the solution was maintained at 10 C the concentration of iodine decreased at a rate of about 0.12 ppm per min and at 25 C the rate of loss was about twice as great. When 0.4% potassium iodide was added the rate of loss was considerably reduced and when 4% potassium iodide was added the loss was negligible. While these results confirmed that iodine is readily volatile in the absence of a large excess of potassium iodide, they indicate that this cannot be the sole cause of the differences previously referred to, because otherwise these differences would be expected to increase rather than decrease with increasing temperature. Possible effects that it was thought might cause the opposite trend were that the excess potassium iodide might dissolve more rapidly at the higher temperature and suppress volatilization more quickly or that iodine might be formed from potassium iodide in acid solution more rapidly at higher temperstures. The latter possibility has, however, been examined but the results obtained so far indicate that it is not of any significance.

The possibilities of errors from the presence of trace impurities in the reagents or in the distilled water are being examined.

Redetermination of Saturation Values.—It seemed from the preceding evidence that the difference between the TDL and TVA saturation values could be partly accounted for by differences in the analytical techniques, but to provide further confirmation saturation values in distilled water have been redetermined using the TVA method for the determination of dissolved oxygen. Substantially the same method of equilibration as was used previously by the TDL group was adopted, except that the water was stirred sufficiently rapidly to ensure that after the first day the concentration of dissolved oxygen would be very unlikely to deviate by more than 0.05 ppm from the saturation value unless the barometric fluctuations were exceptionally severe. The rate of stirring, however, was not sufficient to cause air bubbles to be entrained below the water surface to any great extent. One other difference from the previous procedure was that carbon dioxide was not removed from the water-saturated air passed over the water surface because the work by the TVA group showed this to be unnecessary. The average of four separate determinations in distilled water at 10 C was 11.16 $\pm$ 0.02 ppm that is 0.11 ppm lower

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[21] "Analyst," by G. Knowles and G. F. Lowden, Vol. 78, p. 159, 1953.

than the value published by the TVA group and 0.24 ppm higher than the TDL value. The average of two determinations at 25 C was 8.25 ppm that is 0.07 ppm higher than the TVA value and 0.14 ppm above the TDL value. The differences between these observed values and the TDL figures are substantially the same as the differences found in the comparative tests described previously and, in so far as these differences appear to be due to the different analytical procedure, these results provide indirect confirmation of the TDL figures. The reasons for the differences between the observed values and those reported by the TVA group have not yet been established but, to the extent that these differences are relatively small by comparison with the other larger discrepancies referred to previously, the observed results appear substantially to confirm the TVA work.

Provisional Conclusions.—Though the preceding results do not provide a completely adequate explanation of the differences between the TVA and the TDL values, it appears that a substantial part of the difference may be due to the different analytical procedures used. If, as seems possible, the differences in these procedures are due mainly to the loss of iodine by volatilization, then it would seem that the TVA values are likely to be the more correct. The present work does not throw any light on the differences between the TDL values and those of Morris, and indeed a weakness in the preceding suppositions about loss of iodine by volatilization is that this might also have been expected to occur in the analytical procedure used by the Harvard group. However, direct comparisons between the procedure used by Morris and the TDL method have not yet been made.

If it is established that there are genuine differences between the results given by the different modifications of the Winkler method, then this would raise the wider issue that, to obtain consistent data on rates of aeration from measurements of changes in the concentration of dissolved oxygen, it will be necessary to use a saturation value appropriate to the analytical method. In this connection it will be remembered that one of the arguments used by the TDL group in support of their values was that only by using these values were they able to obtain a linear variation of the logarithm of the oxygen deficit with time, during aeration under constant conditions. They also found that the TDL method appeared to give the same results as the conventional Winkler procedure, commonly used for stream surveys and other similar field work. The preceding results appear to substantiate the latter conclusion, but it would be very interesting to learn if other workers have made any observations on this point. The writers welcome any comments that the TVA group would care to make on this point and on the present line of enquiry being pursued in this Laboratory.

LOW PRESSURE AERATION OF WATER AND SEWAGE[a]

Discussion by Jerzy Gánczarczyk

JERZY GÁNCZARCZYK.[24]—The application of aeration by means of low-pressure air is particularly interesting as the technical confirmation of Ippen's and Carver's observations that this operation takes place mainly by formation and bursting of air bubbles. Moreover, the characteristic high degree of turbulence of such aeration basins, that is connected with this phenomena, and with the flow of large amount of air through a shallow layer of water, may direct our attention to other explanations of aeration effects than those implicated by a non-modified Whiteman's and Lewis' hypothesis.

The author has greatly contributed to fundamental knowledge of low-pressure air aeration, but many problems and questions connected with this subject are still unsolved. The writer's opinions differ in some cases with the author's theoretical formulations and generalisations, but they will not be discussed now. Regarding the author's experimental data, notwithstanding their great value, they are presented in a rather complicated way.

The writer (with J. Suschka) has also taken part in investigations concerning the same subject. Initially, these experiments were carried out in small basin (capacity 0.6 m^3) but further measurements were done in a pilot-plant somewhat similar to that at Nacka (volume equal to 5.4 m^3; depth = 2.0 m, width = 2.25 m). Many data obtained in the latest experiments are in some agreement with author's and writer hopes that their presentation in a slightly different form will contribute to a better understanding of the operation.

[a] September 1960, by Claes H. Fischerström (Proc. Paper 2607).
[24] Dept. of San. Engrg., Technical Univ. at Gliwice, Poland.

Fig. 25 shows the relation between aeration intensity and resulting oxygenation capacities (determined and computed according to Pasveer, with experimental measurement of the oxygen saturation point) for different depths of air distributor and with or without the aid of the circulation wall which was equal to 1/3 of basin depth.

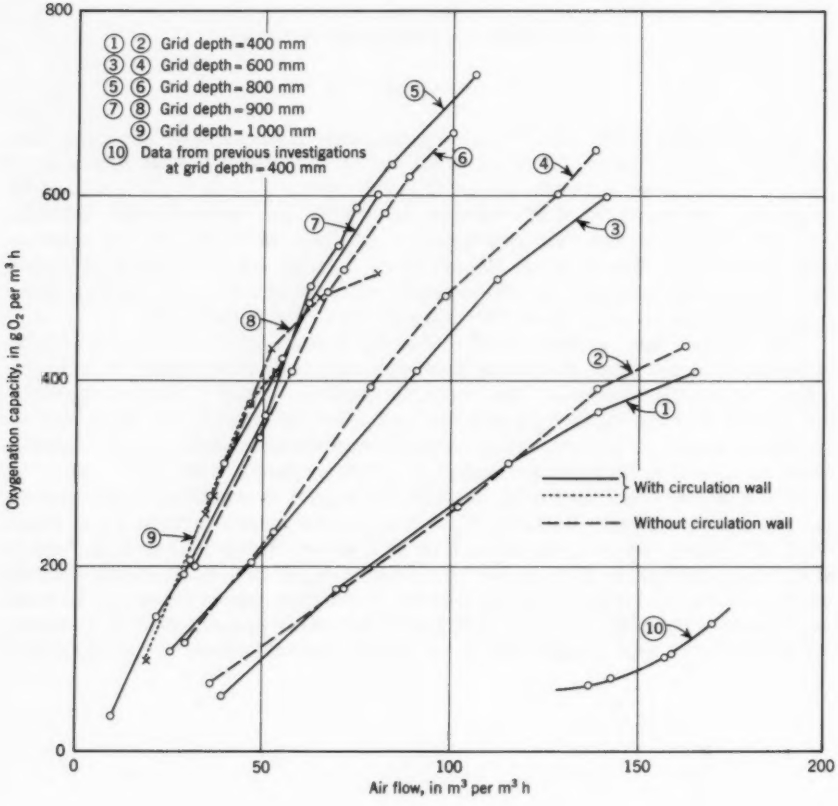
① ② Grid depth = 400 mm
③ ④ Grid depth = 600 mm
⑤ ⑥ Grid depth = 800 mm
⑦ ⑧ Grid depth = 900 mm
⑨ Grid depth = 1 000 mm
⑩ Data from previous investigations at grid depth = 400 mm
With circulation wall
Without circulation wall
Oxygenation capacity, in g O_2 per m^3 h
Air flow, in m^3 per m^3 h
0
50
100
150
200
400
600
800

FIG. 25.—COMPARISON OF OXYGENATION CAPACITIES FOR VARIOUS AIR DISTRIBUTOR DEPTHS VERSUS AIR FLOW

On the basis of these results it may be stated that for the given air distributor:

1. Oxygenation capacities increase with the increase of air flow (for some ranges of air flow almost proportionally) and with the increase of immersion depth to the depth of 800 mm;

2. Immersions of air distributor greater than 800 mm (for example, 900 mm or 1000 mm) give only slightly better results;
3. Influence of the circulation wall on oxygenation capacities of the unit is rather complex: for some immersion depths it is beneficial (for example, for 800 mm) but for others it may cause decrease of OC; and

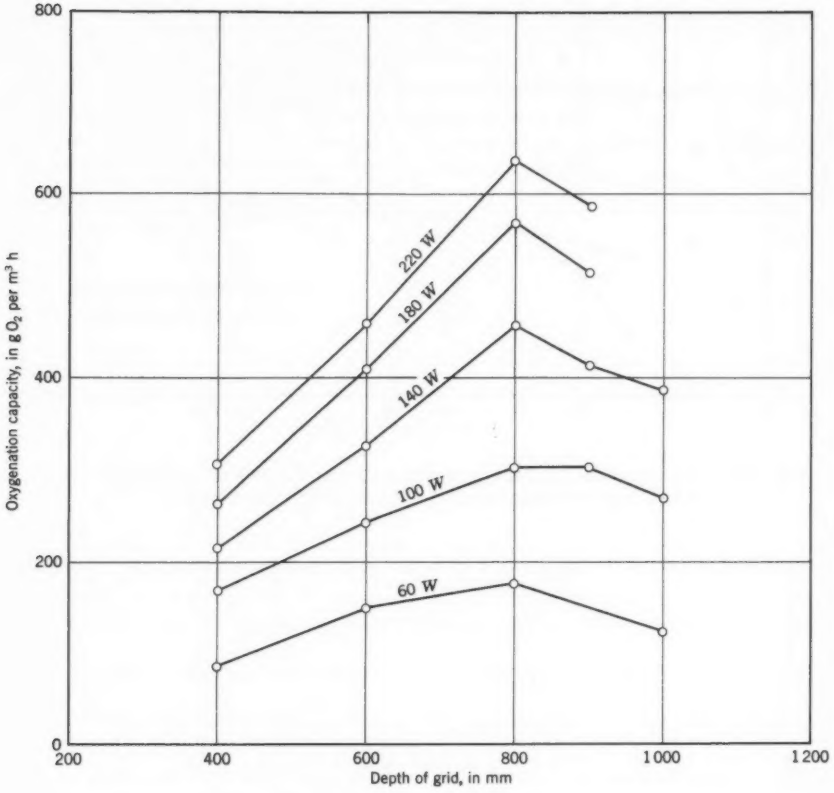

FIG. 26.—AIR UTILISATION OF LOW-PRESSURE AERATION

4. Experiments carried out in too small basins and with the aid of incorrectly constructed air distributors may give decisively smaller oxygenation capacities (for example, points (10) in Fig. 25).

Fig. 26. shows the comparison of oxygenation capacities for various netto values of power at the studied air distributor depths. The aeration economy

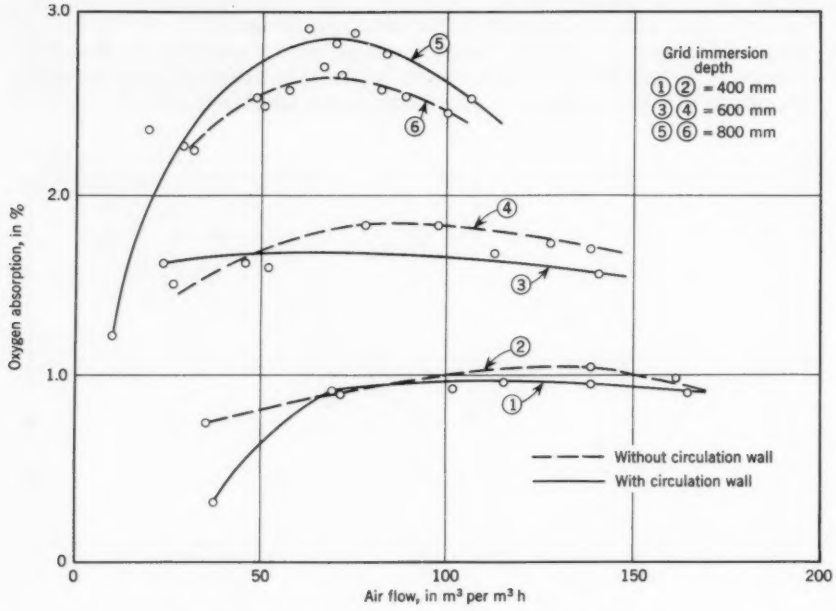
Oxygen absorption, in %
Air flow, in m³ per m³ h
Grid immersion depth
① ② = 400 mm
③ ④ = 600 mm
⑤ ⑥ = 800 mm
Without circulation wall
With circulation wall

FIG. 27.—COMPARISON OF OXYGENATION CAPACITIES FOR VARIOUS NETTO VALUES OF POWER VERSUS GRID IMMERSION DEPTH

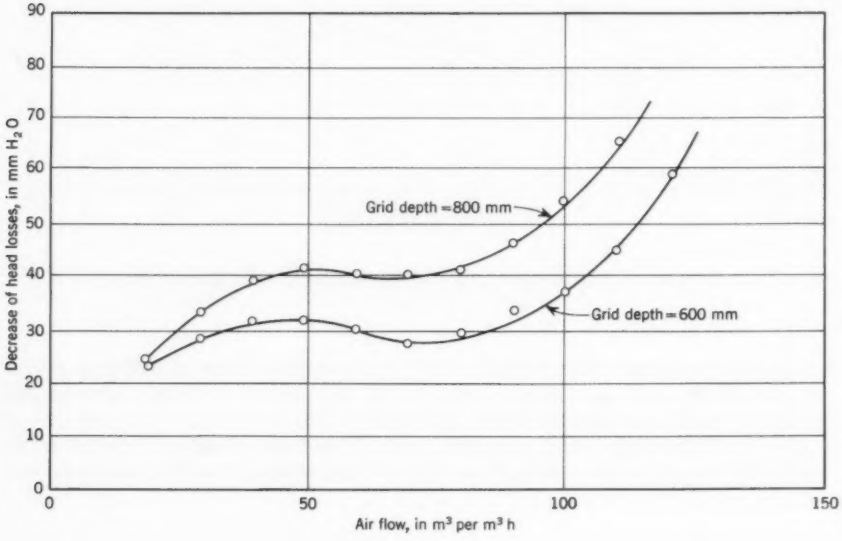

FIG. 28.—DECREASE OF AIR DISTRIBUTION HEAD LOSSES VERSUS AIR FLOW

optimum at the 800 mm depth (or close to this value) is quite obvious. At this depth of air distribution the second optimum of aeration efficiency was stated for some range of air flow. It is equal to 3330 g O_2 per kw hr.

The prior statement is also confirmed by the data presented in Fig. 27.

Some views on hydraulic properties of studied unit may be drawn from the decreases of head losses of air distributor at various immersion depth and at various flow of air. It may be assumed that these values are strictly connected with the efficiences of hypothetical mammoth-pump in aerated part of the unit. Fig. 28. gives data concerning this fact.

The final conclusions seem to be:

1. The proper construction of air-distributor is of first importance for the efficiency and economy of this aeration system; and
2. Investigations and studies ought to be carried out in models of basins with width and depth dimensions close to technical scale.

ERRATA

Journal of the Sanitary Engineering Division

Proceedings of the American Society of Civil Engineers

Discussion by C. H. J. Hull, November 1960, Proc. Paper 2666, of "Oxygen Balance of an Estuary" by Donald J. O'Connor.

p. 106. In Eq. 22 the term T' - T is a superscript to the term θ and should be enclosed in parentheses.

p. 107. In line 6 of the third full paragraph, insert a period after the item . . . and H. B. Gotaas, 34) and follow this with the word If.

p. 110. The first column of the tabulation dealing with reaeration coefficients should read as follows

River Reach, in Miles
33.85 - 32.43
32.43 - 31.45
31.45 - 30.43

p. 110. Change lines 3 and 4 of the third full paragraph to read as follows:

W. C. Purdy (40) on the Potomac River estuary, Purdy (41) on New York Harbor, W. Rudolfs and H. Heukelekian (45), C. K. Calvert (5), Purdy (42)

p. 117. In reference 14, in line 3, insert the number 10 in the blank space.

p. 119. In reference 48 add a line 5 as follows:

International pour l'Exploration de la Mer, Vol. 144, April, 1958, pp. 13-14.

p. 120. In reference 55 add a line 5 as follows:
pp. 709-711.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Department of Conditions of Practice are identified by the symbols (PP). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper number are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 2703 is identified as 2703(ST1) which indicates that the paper is contained in the first issue of the Journal of the Structural Division during 1961.

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MARCH: 2393(IR1), 2394(IR1), 2395(IR1), 2396(IR1), 2397(IR1), 2398(IR1), 2399(IR1), 2400(IR1), 2401(IR1), 2402(IR1), 2403(IR1), 2404(IR1), 2405(IR1), 2406(IR1), 2407(SA2), 2408(SA2), 2409(HY3), 2410(ST3), 2411(SA2), 2412(HW1), 2413(WW1), 2414(WW1), 2415(HY3), 2416(HW1), 2417(HW3), 2418(HW1)[c], 2419(WW1)[c], 2420(WW1), 2421(WW1), 2422(WW1), 2423(WW1), 2424(SA2), 2425(SA2)[c], 2426(HY3)[c], 2427(ST3)[c].

APRIL: 2428(ST4), 2429(HY4), 2430(PO2), 2431(SM2), 2432(PO2), 2433(ST4), 2434(EM2), 2435(PO2), 2436(ST4), 2437(ST4), 2438(HY4), 2439(EM2), 2440(EM2), 2441(ST4), 2442(SM2), 2443(HY4), 2444(ST4), 2445(EM2), 2446(ST4), 2447(EM2), 2448(SM2), 2449(HY4), 2450(ST4), 2451(HY4), 2452(HY4), 2453(EM2), 2454(EM2), 2455(EM2)[c], 2456(HY4)[c], 2457(PO2)[c], 2458(ST4)[c], 2459(SM2)[c].

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JULY: 2541(ST7), 2542(ST7), 2543(SA4), 2544(ST7), 2545(ST7), 2546(HY7), 2547(ST7), 2548(SU2), 2549(SA4), 2550(SU2), 2551(HY7), 2552(ST7), 2553(SU2), 2554(SA4), 2555(ST7), 2556(SA4), 2557(SA4), 2558(SA4), 2559(ST7), 2560(SU2)[c], 2561(SA4)[c], 2562(HY7)[c], 2563(ST7)[c].

AUGUST: 2564(SM4), 2565(EM4), 2566(ST8), 2567(EM4), 2568(PO4), 2569(PO4), 2570(HY8), 2571(EM4), 2572(EM4), 2573(EM4), 2574(SM4), 2575(EM4), 2576(EM4), 2577(HY8), 2578(EM4), 2579(PO4), 2580(EM4), 2581(ST8), 2582(ST8), 2583(EM4)[c], 2584(PO4)[c], 2585(ST8)[c], 2586(SM4)[c], 2587(HY8)[c].

SEPTEMBER: 2588(IR3), 2589(IR3), 2590(WW3), 2591(IR3), 2592(HW3), 2593(IR3), 2594(IR3), 2595(IR3), 2596(HW3), 2597(WW3), 2598(IR3), 2599(WW3), 2600(WW3), 2601(WW3), 2602(WW3), 2603(WW3), 2604(HW3), 2605(SA5), 2606(WW3), 2607(SA5), 2608(ST9), 2609(SA5)[c], 2610(IR3), 2611(WW3)[c], 2612(ST9)[c], 2613(IR3)[c], 2614(HW3)[c].

OCTOBER: 2615(EM5), 2616(EM5), 2617(ST10), 2618(SM5), 2619(EM5), 2620(EM5), 2621(ST10), 2622(EM5), 2623(SM5), 2624(EM5), 2625(SM5), 2626(SM5), 2627(EM5), 2628(EM5), 2629(ST10), 2630(ST10), 2631(PO5)[c], 2632(EM5)[c], 2633(ST10), 2634(ST10), 2635(ST10)[c], 2636(SM5)[c].

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DECEMBER: 2668(ST12), 2669(IR4), 2670(SM6), 2671(IR4), 2672(IR4), 2673(IR4), 2674(ST12), 2675(EM6), 2676(IR4), 2677(HW4), 2678(ST12), 2679(EM6), 2680(ST12), 2681(SM6), 2682(IR4), 2683(SM6), 2684(SM6), 2685(IR4), 2686(EM6), 2687(EM6), 2688(EM6), 2689(EM6), 2690(EM6), 2691(EM6)[c], 2692(ST12), 2693(ST12), 2694(HW4)[c], 2695(IR4)[c], 2696(SM6)[c], 2697(ST12)[c].

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JANUARY: 2698(PP1), 2699(PP1), 2700(HY1), 2701(SA1), 2702(SU1), 2703(ST1), 2704(ST1), 2705(SU1), 2706(HY1), 2707(HY1), 2708(HY1), 2709(PO1), 2710(HY1), 2711(HY1), 2712(ST1), 2713(HY1), 2714(PO1), 2715(ST1), 2716(HY1), 2717(SA1), 2718(SA1), 2719(SU1)[c], 2720(SA1)[c], 2721(ST1), 2722(PP1)[c], 2733(PO1)[c], 2724(HY1)[c], 2725(ST1)[c].

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MARCH: 2756(HY2), 2757(IR1), 2758(AT1), 2759(CO1), 2760(HY2), 2761(IR1), 2762(IR1), 2763(HY2), 2764(ST3), 2765(HY2), 2766(HW1), 2767(SA2), 2768(CO1), 2769(IR1), 2770(HY2), 2771(SA2), 2772(HY2), 2773(CO1), 2774(AT1), 2775(IR1), 2776(HY2), 2777(HY2), 2778(SA2), 2779(ST3), 2780(HY2), 2781(HY2)[c], 2782(HW1)[c], 2783(SA2)[c], 2784(CO1), 2785(CO1)[c], 2786(IR1)[c], 2787(ST3)[c], 2788(AT1)[c], 2789(HW1).

c. Discussion of several papers, grouped by divisions.

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